A Shoreface Morphodynamic Zonation and the Equilibrium Profile Variability on the Northern Coastline of Rio Grande do Sul, Brazil

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ABSTRACT

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The sedimentary distribution variation of a 60 km shoreface tract on the northern coastline of Rio Grande do Sul shows a relationship between distinct morphodynamic zones. This relationship was based on 11 beach and shoreface equilibrium profiles of up to 15 m of water depth, at 55 shoreface and 4 beach sedimentary samples. Textural variations displayed contrasting dynamics that were revealed by the distinct designs and shapes of the profiles. These were extended and taken over the closure depth (7.5 m for the area). They revealed a dissipative beach sand systems, with a shape factor of m = 0.74. A high variability was identified, reflecting the erosion tendencies on this coastline segment. Statistical sedimentary parameters for such sedimentary distributions permitted the identification of two main sediment facies: (A) sandy facies: (B) muddy sand with bioclastic gravel facies. Cross-shore variations show three morphodynamic zones: high energy (2 to 4 m), transitional (6 to 9 m) and low energy zones (11 to 16 m), and classifying, high, intermediate and low shoreface patterns. The morpho-sedimentary distribution defined three sections: (a) North, having moderate slope profiles (0.010) with less variability in sediment fractions, (b) Center, showing a wide range of profiles (from 0.008 to 0.010) with a finer and coarser sedimentary distribution and (c) Center-South, identifying much steeper slope (0,017) with seaward fining sediments. Morphodynamic shoreface-inner shelf boundaries (toe) were shown at 18 m at the North section, changing to 16 to 25 m at the Center and Center-South sections.

ADITIONAL INDEX WORDS: *Equilibrium profile, dissipative beaches, sediments.*

INTRODUCTION

Different from the good knowledge about the continental shelf and coastal plain of Rio Grande do Sul, the shoreface is not well known. This work presents a correlation between the beach equilibrium profiles and the sedimentary distribution, that was identified using 11 profiles, taken from the beach and shoreface of this coastline segment, based on geology and bathymetry data.

The results are conceived applying the equilibrium profile concept (DEAN, 1977) and on statistical handling of the sedimentary fractions and external limits of the shoreface dynamics. According to PILKEY (1998), the shoreface, the concave part of the upper segment of the inner shelf is a fundamental sector to understand coastline evolution, erosion rate alterations and to forecast impacts relating to sea level variations.

Shoreface zonations, defined by morphology, sedimentary distribution and hydrodynamic processes, are especially important for beach profile evolution studies (GULLIEN and PALANQUES, 1997).

The shoreface sediments tend to be finer with depth (SWIFT, 1976; NIEDORODA *et al.*, 1985) mainly, due to the transport energy decrease. But this grain, fining out seaward, is not monotonic, showing a sharp variation close to the coastline (LARSON, 1991).

Textural classes of sediments can be considered as natural tracers and the grain size distribution is representative of the long term shoreface dispersion patterns (LIU and ZARILLO 1989). ZENKOVICH (1967) considers that the equilibrium of a dynamic zone is defined by the size of the grain that is set in the shoreface sector, on the fraction that represents its peak of abundance. Based on these parameters, GULLIEN and PALANQUES (1997) established a morphodynamic zonation for the Ebro Delta shoreface, defined by morphology, hydrodynamics and sediment distribution.

Beach Equilibrium Profile Concept

It is commonly known that beaches are the product of a complex system of forces and processes. Beach profiles present a complex form due to the presence of bars and throughs, steeped at the beach line, with a progressive seaward gradient decrease.

Although very controversial, by the complexities of the interacting morphologic and hydrodynamic variables, the concept of an equilibrium profile has been widely employed. The constant search for model applications in this sector permits the testing under real conditions, at low costs and quickly. For BRUUN (1954, 1962, 1988); DEAN (1977,1987,1991, 1997), DUBOIS (1992); MOORE (1982), the equilibrium profile concept can be applied to many coastlines to describe actual profile characteristics.

Bruun's Rule, as it has become known, was conceived by BRUUN (1954) it has also been used by DEAN (1977). This equation considers that the beach equilibrium profile is a result of the energy balance from two unknown parameters, based on distance (m) and depth (y) data and that the depth increases seaward in the proportion of (y2/3), being:

$$h = Ay^m \qquad (1)$$

Where "h" is the depth (in meters) and "y" is equivalent to the distance from the beach (in meters). "A" and "m" are empiric coefficients based on representative profiles. The shape factor "m" is a modal state function of the beach and the scalar parameter "A", relates to grain size of the deposition velocity (DEAN, 1987).

WRIGHT *et al*. (1982, 1991) extended this definition up to the inner shelf. BOON and GREEN (1988) attributed a value of ½ for "m", values applied to reflexive beaches, compared to those studied by DEAN (1977). FACHIN (1998) studied the southern part of RS coastline shoreface and inner shelf, employing m=0,44. GRUBER *et al*. (2000) found a better adjustment for m=0,74, with more dissipative beach models.

Study Area

Rio Grande do Sul has a 600 km open coastline dominated by waves and micro tides of 0.47 m, with only two discontinuities: Patos and Tramandaí lagoon inlets. The northern RS coastline beaches are 60 m in width, formed of fine well selected quartz sands, classified as intermediate and dissipative beaches (WESCHENFELDER *et al.*,1997; TOLDO JR. *et al.,*1993).

This coastline is influenced by the Southeastern Atlantic Subtropical Anticyclone (CALLIARI *et al.,* 1998; TOZZI, 1997), and is frequently submitted to storm surges, that increase the sea level to up to 1.50 m. The waves show a period of 9 seconds and a maximum hight (He) of 4.5 m (ALMEIDA *et al.* 1997).

The erosional processes have been discussed by CALLIARI *et al.* (1998) as resulting from wave action storms. TOMAZELLI *et al.* (1998, 2000) consider erosive processes as the latest response to a relative sea level variation. TOLDO JR. *et al.* (1999) has identified rates and erosional sectors along the coast. DILLENBURG *et al.* (2000) consider different shoreface gradient responses and its Holocene barrier variability configuration evolution throughout RS coastline. One of these transition sectors was found in the studied area, corresponding to a 60 km coastline strip, from the Capão da Canoa to Jardim do Éden beachlines (GRUBER and NICOLODI, 1998; GRUBER *et al.,* 2000) (Figure 1).

METHODS

55 shoreface sedimentary and 4 of beach face samples were collected at eleven profiles, plotted from the North (profile 15)(N = 6708907 m e E = 596659 m), to the South (profile 5) (N = 6676107 m e E = 583837 m) (Figure 1).

The adopted georeferenced cartographic base, for the coastline positioning, considered TOLDO JR. *et al.* (1999). The depths were obtained by echo sounding. Sediments were collected employing a *Dietz la fond* sampler, 5 samples for each profile, in depth strips ranging from the surf zone to 15 m.

Statistical parameters were used to detail the sand fractions and sedimentary distribution collected at comparable depths: 2 a 4 m; 6 a 7 m; 9 a 10 m; 12 a 13 m; e 14 a 16 m. The purpose was to better evaluate the textural behavior of grain size in relation to the depths. ALMEIDA *et al.* (1999a) attributed the closure depth of $d_1 = 7,5$ m to the area, based on circulation and wave patterns of HALLERMEYER (1981) and BIRKENMAIER (1985).

RESULTS

Equilibrium Profile: Dean Model Application

Considering DEAN (1977), the shape factors of the eleven profiles were adjusted to m = 0,74, indicating a dissipative beach system related to the pattern proposed by the author. The results were comparably up to 16 m. Some contrasting patterns were observed.

In general, the comparative analyses of the overlaying measured and estimated profiles, related to the observed fit, indicated that these beach systems are in sediment balance equilibrium.

Despite the small coastline segment that was studied, great variabilities of the shoreface profile behaviors and sedimentary distributions were observed.

The estimated profile designs resulted from the grain size variation of each profile. These variations were represented by sedimentary fractions that vary from coarser fractions of Md = 2,67 to finer fractions of Md = 3,34.

Shoreface: Morphology and Sediments

The parabolic profile and the continuous grain fining with depth are the typical characteristics of an equilibrium profile (DEAN, 1977; DEAN, 1991). To note, some deficit and superavit sectors were observed, correlating with the granulometric fraction dynamics that composed these sedimentary accumulations. This makes it possible to evaluate the hydrodynamic energy conditions.
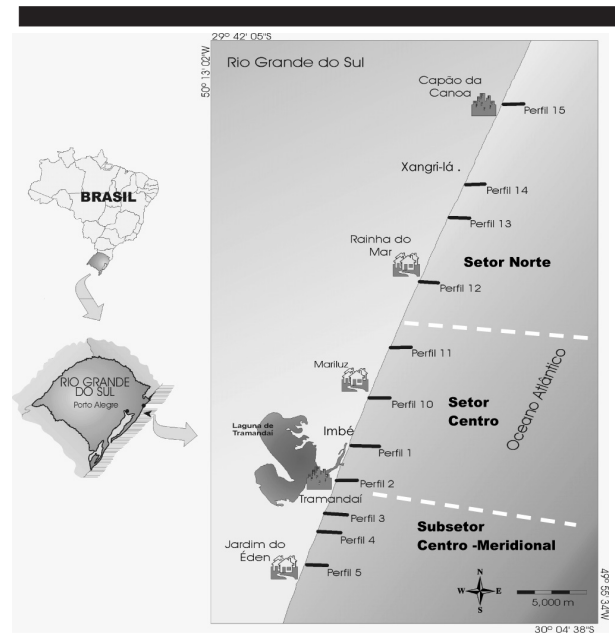

Figure 1. Localization of the study area and the three morphodynamic sections North, Center and Center-South.

O "equilibrium" between morphology and sedimentary distribution of the shoreface is disturbed by the presence of bars, ancient deposit reworking, and by winnowing. These factors promote the sedimentary textural parameter change (GULLIEN and PALANQUES, 1997).

In general, for the Tramandaí region, estimated and measured shoreface profile behaviors show an erosional deficit tendency for the shallower sector. This suggests a lack or loss of sediments on the negative (ϕ) coarser fractions of the distribution.

On the other hand, considering the dominant distribution of fine sediments, increased by coarser fractions, the lower shoreface presents a superavit tendency. Such fractions, that are not transported under fair weather conditions, were probably supplied by storm surges or reworked by winnowing of old inner shelf deposits.

Shoreface morphology aspects, given by bathymetric survey, revealed a medium gradient, from 0.010 to 0.017. The most common slopes, being from 0.006 to 0.011. In general, profiles present greater slopes at the upper shoreface, 3 to 4 m of surf zone, gradients of around 0.021.

This behavior permitted enough detailing to classify the shoreface morphodynamics as a "transitional or intermediate shoreface". Based on the observed morphologic and dynamic patterns, three main gradient standards are proposed and associated to the bellow listed sectors, see also Figure 2.

- High Gradients: 0.021 to 0.011 from the surf zone to 4 m / 6 m, on the upper shoreface;
- Low Gradients: 0.006 to 0.004 in discontinuous patterns associated to bottom facies in intermediate sectors located from 6 m /11m, on the transitional shoreface;
- Moderate or Intermediate Gradients: 0.011 to 0.006 associated to the deeper parts of the lower shoreface from 11 m to 15 m (Figure 2).

In general, the profiles vary from the two main bar systems, being the proximal bar represented by the sled survey, done at Tramandaí (ALMEIDA *et al.*, 1999b). This survey became the standard to compare all other measured shoreface profiles. The second, an external bar system varied in depth from 4 / 6 m to 8 / 11 m, as response of morphology and sediment occurrences, shown on the break of the slope (Figures 1 and 2).

GULLIEN and PALANQUES (1997) consider that the internal and external bars are the most important features of this nearshore system. This fact was also observed in the region of Tramandaí, where the bar systems are associated to a dissipative beach
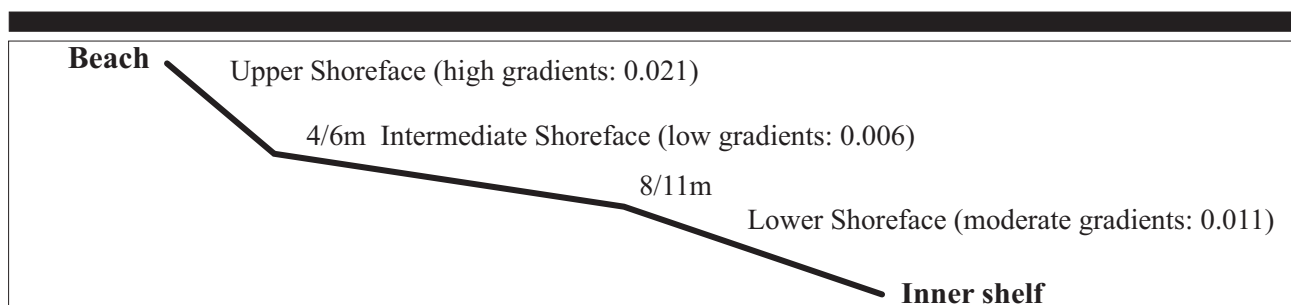
Figure 2. The three main shoreface gradient standards observed and the proposed classification: Upper, Intermediate or Transitional and Lower shoreface.

model, in accordance with SHORT (1984). Important morphological features are rarely identified in the deepest sectors of the profiles, only small variation patterns have been registered at these depths

Sedimentary Analysis and Statistic Testing

The sediments collected on the beach system, both on the berm and on the beach sector (Md = 2.93), are dominantly composed of fine grain sand quartz. Size varies from fine to very fine sand on the shoreface, frequently having silt components (Md = 3.28) or bioclastic gravel (Md = 2.94) (GRUBER and NICOLODI, 1998).

The spatial distribution of the sediments was characterized by the textural fraction peaks, which occurred on the profiles and were detailed in the statistical parameters.

The shoreface grain sizes of the northern coastline were set at the textural class of sand and fractionally vary from 1.6 to 8.8 , with a mean (Mz) from 2.62 to 3.38**,** standard deviation () from 0.26 to 0.61, skewness (Sk) from 0.32 to 0.13 and curtosis (Kkg) from 0.73 to 1.39. The average grain size (Mz) presents a tendency to fine out with increasing depth, from the beachline to depths greater than 6 m, suffering a variation (Mz) from 2.62 to 3.38. These values are very close to the median (Md), which reveal variations from 2.67 e 3.34. The standard deviation () decreases from the beach until half of the profile (8 /11 m) and increases in the samples taken deepest (14/16 m). The skewness variation distribution (Sk) decreases from minimum negative values in the beach (-0.006) to values close to 0 or positive (0.023) at the profiles external section (8/11 m), returning to negative (-0.14) at the deepest sectors (14 /16 m).

A general view of the sediment grain size distribution indicates some trends. This fact was also found by GULLIEN and PALANQUES (1997): (a) sediments tend to be finer and poorly selected; (b) sediments change from an excess of coarser fractions (shell fragments) to an excess of finer fractions (from a negative skewness to a positive one) and (c) the grain size dispersal around the modal size increases (curtosis decrease).

Although, these tendencies are locally interrupted, presenting textural variations all through the extension of the shoreface, the relations between the parameters basically defined two main sediment facies: **Facies A -** sandy with a mean Mz (from 2.62 to 3.10); well selected standard deviation; from negative assymetry to perfectly symmetric; and low curtosis; **Facies B** - finer sediments with a mean Mz (from 3.11 to 3.34); moderately selected; slightly positive skewness; and high curtosis.

These sediment facies **A** and **B** define high and low energy aspects related to other areas. Their limits on the shoreface are not clearly defined by this relation, but both present transitional aspects.

The spatial facies distribution **A** and **B,** as well as the textural fractions in the profiles and throughout the area were detailed by histograms over each profile. Based on these types, textural variation and spatial distribution was observed, also being possible to define 3 morphdynamic sectors: **Sectors North**, **Central** and the transitional characteristics, **Sector Center-South** (Figures 1 and 3).

The North Sector presents moderate gradient profiles (0.010)

with an excellent adjustment, less textural fraction variability and a grain fining seaward increase. The Central Sector shows variable gradient profiles (0.008 a 0.010), alternating fine and coarse distributions. Central-South Sector, a transitional sector, has steep profiles (0.017) with little textural fraction variability. It has also a seaward progressive grain fining, although showing discrepant adjustments bellow the 10 m depth (Figures 1 and 3).

Shoreface Morphodynamic Zonation

Based on the morphological characteristics as well as the sedimentary composition and distribution, a shoreface morphodynamic zonation has been offered. Gullien and Palanques (1997) proposed a similar description, in which the mixtures correlated the textural fractions to the hydrodymics. This zonation could be breached by geological heritage.

This zonation considers the set of transversal variations on the beach profiles, identifying 3 dynamic zones: **high dynamic zones, transitional zones and low dynamic zones**.

1) High Dynamic Zones: correspond to the shallower zone (up to 4/6 m), with sediments from the upper high energy shoreface f**acies A**, characterized by steeper slopes and great bar and trough mobility. The skewness distribution has a negative tendency as does the profile design. This indicates that the finer fractions are removed from the sediments by wave washing, showing a fit deficit (Figure 2).

2) Transitional Zone: configured by a transitional strip on the intermediate shoreface (6 to 11 m) occupied by **facies A** e **B** sediments. Frequently configuring a distal bar in a dissipative pattern and with fit superavit on the estimated profiles. In this zone the wave incidence continuously affects the bottom sediments, transporting and sorting out different grain sizes, mainly during major storms.

3) Low Dynamic Zone: this is related to the deepest zone (bellow 11 m) on the lower shoreface, shown by **facies B** low energy sediments, a bimodal distribution: (B1) storm mobilized quartz sand and shells; (B2) fair weather deposited muds.

The expected one beach pattern system for the northern coastline of Rio Grande do Sul (60 km) was not confirmed. The overlying shoreface profiles characterized morphology contrasts and trends that corroborated with TOLDO JR. *et al.* (1999).

Correlated erosion/accretion tendency sections of coastlines, described by TOLDO JR. *et al.* (1999), were herein discussed, based on comparative analyses of the shoreface profiles and their consequence on beach systems. The surveyed depths of up to 15 m permitted a behavior comparison among profile sections. The comparative analyses of these profiles reveal a series of similarities and contrasts in their designs, as well as in the deficit or superavits throughout the beach systems.

To note though having similar patterns, in which beach systems are basically composed of fine quartz beach sands to very fine shoreface sands with eventually are enriched by mud and shell fragments, the profiles' responses to the morphodynamics were distinct. Considering individual case studies, the profiles present deficit strips normally observed in the upper shoreface. These are compensated by superavit strips at the intermediate and lower shoreface. In general, the net fit for each beach/shoreface system is in equilibrium.

The contrasts among the morphodynamic sectors reflect erosive or accresive conditions for the coastline (TOLDO JR. *et al.*, 1999) (Figures 1 and 3).

Profile 14 (Xangri-lá) **(North Sector)** shows a perfect adjustment throught the whole shoreface profile. This is associated to a **moderate erosional trend coastline pattern** (TOLDO *et al.*, 1999). The sled profile ALMEIDA *et al.* (1999b), when overlapped with the surveyed shoreface profile, presents a break in the contact (Figures 1 and 3).

Profile 2 (Tramandaí) **(Center Sector)** This sector is found at a transitional, exhibiting an erosive adjustment on the upper shoreface, associated to a fine sediment dynamic environment, that comes from the Tramandaí Lagoon. On the other hand, the lower shoreface presents an accretional feature correlated to coarse sediment fraction increase (shell fragments). This coastline section is classified as a **great erosional trend pattern** (TOLDO JR. *et al.*,1999)**.** The surveyed sled profile presented a smoth conta with the measured shoreface profile (Figures 1 and 3).

Profile 5 (Jardim do Éden) **(Center-South Sector)** suggests an erosive upper shoreface. The deficit designs could be related to local and eventual storm surge mud supply occurrences on the beach face. This profile presents accretion at the intermediate shoreface and a new erosive adjustment at lower shoreface. TOLDO JR. *et al.* (1999) classified this section as a **high erosive trend pattern** (Figures 1.and 3).

Shoreface Inner shelf Boundaries

Aspects on external limits of shoreface action that are discussed in the literature: (a) a hydrodynamic limit proposed for the closure depth, usually from 8 to 10 m; and (b) a morphological limit, at a gradient variation on the base of the shoreface (toe), at the limit with the inner shelf, varying from 15 to 25 m.

Authors discuss moderate energy beaches that present: a shoreface toe at 25 m along the New York coastline, USA, (NIEDORODA, *et al.*,1984); 15 m at Duck, North Carolina, USA (WRIGTH, 1991); the 10 to 25 m toe off the southeastern Australian coast (SHORT, 1984) and 20 to 30 m for the northeastern coastline off North Island , New Zealand (HILTON and HESP, 1996).

In the northeastern segment of Rio Grande do Sul coastline this limits are very well defined and situated at 18 m toe at the northernmost sector. A transitional configuration with, undefined breaches in the slopes of the strips change, from 16 to 25 m showing a parabolic profile with an erosional design at Center and Center-South Section (GRUBER and NICOLODI, 1998; NICOLODI and GRUBER, 1998)

CONCLUSIONS

The Rio Grande do Sul coastline presents a general dissipative pattern with great shoreface variability. Such variations reflect from both the profiles'morphodynamics and sediment supply (of geological inheritance). This made it possible to define three morphodynamic sectors: North, Center and Center-South.

Close to the shoreface-innershelf boundaries (toe), slope and sediment changes become more evident.

A morphodynamic shoreface-inner shelf boundaries (toe) correlationship is discussed in a follow up paper, where, the main characteristics to be discussed are: the 18 m North section shoreface point toe that shifts to a diffuse strip toe at the 16 to 25 m band, Center and Center-South sections.

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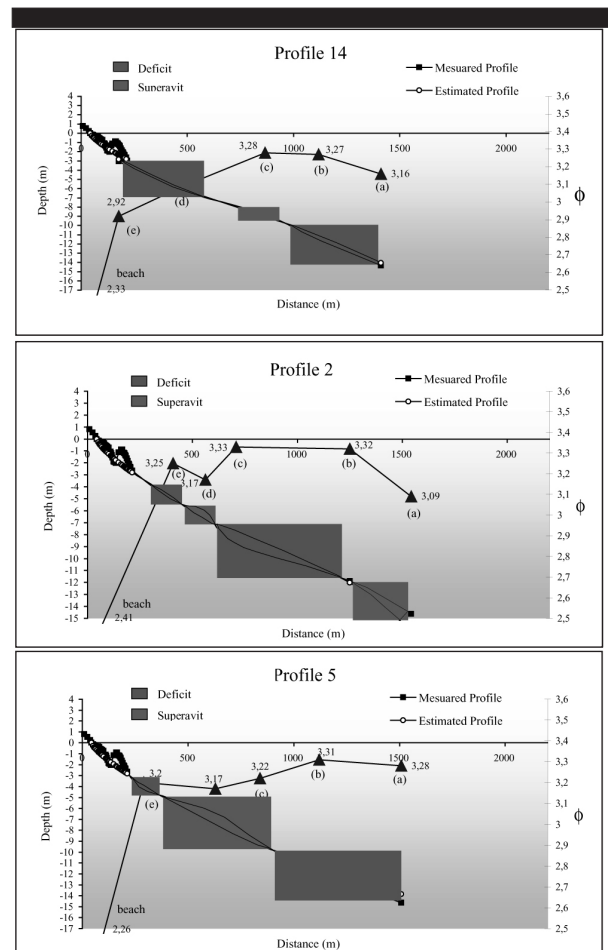

Figure 3. Contrasting North, Center and Center-South sections equilibrium beach/shoreface profiles. The estimated and morphologic overlapping profiles show different shoreface design zones of deficit and supervit in the fit.(due to physical obscures the view is upside down).

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