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Morphodynamic Limits of Shoreface and Inner Shelf at the Northern Coast of Rio Grande do Sul, Brazil

N. L.S. Gruber †; I.C.S. Corrêa ‡; J. L. Nicolodi ∞; E.G. Barboza §

† CECO & Departamento de Geografia, Instituto de Geociências / Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS. Brazil

‡ CECO & Departamento de Geodésia, Instituto de Geociências / Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS. Brazil
iran.correa@ufrgs.br

∞ CECO & Bolsista CNPq Programa de Pós Graduação em Geociências PPGEO / IG, Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS. Brazil
jl.nicolodi@bol.com.br

§ CECO & Bolsista ANP Programa de Pós Graduação em Geociências PPGEO / IG, Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS. Brazil
eduardo.baroza@ufrgs.br

ABSTRACT

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Detailed geology, bathymetry and sonographic data have been obtained over 80 km of the northern shoreline section of Rio Grande do Sul, the southernmost state of Brazil. This data was collected up until 50 m water depth, to determine the outer limits of the shoreface-inner shelf sediment exchange and evolution. Integrated data of 278 bottom samples, taken from the inner shelf, including 27 cores and 11 transverse shoreface bathymetric profiles, depth of up to 15 m, were analyzed. Geoprocessing data patterns show a regular bottom with gentle slopes, identifying three distinct morpho-sedimentaty sections: North, Central and South. The North and South sections reveal a heterogeneous pattern in the morphology and sedimentary distribution, contrasting with the South section, which has a more gradual sedimentary distribution fining out seaward. Correlations among textural statistic parameters, maps and sonographic records revealed variations, classifying 8 main facies. Bathymetric extended profiles, from the shoreface to the depth of 40 m, characterized the morphological shoreface-inner shelf dynamic boundaries (toe) at 18 m on the Northern section, from 16 m to 25 m at the Central and South sections. The shoreface shows marine dynamics over the geological control. Core facies and fauna show a morpho-structural and geological inheritance, responding to a coastline translation displacement. This process was responsible for the local variations of palimpsest and relict sediments, affecting ancient topography control of the coastline translation and past still steady sea levels, of the barrier variability, during the last Holocene Transgression.

ADDITIONAL INDEX WORDS: *Continental shelf, side scan sonar, sediments.*

INTRODUCTION

The continental shelf and the coastal plain are well known in Rio Grande do Sul (RS), different from the shoreface, that depends on more detailed studies to better define its evolution and morphodynamic limits. Integrated analysis of geological data; bathymetric and side scan sonar records, correlated to geological cores and shoreface profiles, were done on the northern coast of RS. This data was obtained through the project developed by Petrobras and the Universities Ufpr, Ufsc, Furg, Ufrgs. The results discuss the regional morphodynamics and geolgical characteristics of the shoreface as well as their limits with the inner shelf.

The shoreface, according PILKEY (1998), is probably the last part to be understood of the marine system dynamic processes for the nearshore, due to the complexity of its natural dynamics, especially during the action of major storms. The understanding of these processes concern coastal evolution history as well as sea level impact prediction and changes. Also, offering parameters for coastal erosion rates and coastal engineering, beach nourishment, sand and gravel exploitation (bioclastic) on the continental shelf (NIEDORODA *et al.*, 1984; RIGGS, *et al.*, 1995; HILTON and HESP,1996).

Study Area

Rio Grande do Sul is characterized by an open coast that extends for more than 600 km, dominated by waves and micro-tides of 0,47 m, with an extensive continental shelf. Both show very well preserved features and have detailed paleogeographic history of the Quaternary transgressive-regressive events (MARTINS, 1996, 1998, 1999; MARTINS, *et al.*, 1972; CORRÊA, 1994, 1996; VILLWOCK, 1984, 1994; VILLWOCK and TOMAZELLI, 1995). This coast presents four outlets with only muddy sedimentary contributions: Mampituba and Chuí rivers, at the North and South limits, and the Patos and Tramandaí lagoon inlets. Sea conditions are variable, mainly during storm surges, due to the passage of frontal systems, that rise the sea level up to 1,50 m (ALMEIDA *et al.*, 1999) (Fig 1).

The study area corresponds to the northern coast of RS, lat. 30º00`00"S and long. 50º00`00"W (E 5577345 m to 612545 and N 6662410 m to 6708760 m UTM central meridian 51ºW) in a polygon of 80 km along the coast, for 30 km off shore, until the limit of the isobaths of 50 m (Fig. 1).

Geology of the Area

The regional geology is configured by the Província Costeira do Rio Grande do Sul (VILLWOCK *et al.,* 1984) composed of: (a) Uruguaio-sul-riograndense Pré-Cambrian Shield and (b) Pelotas Basin, constitute by the coastal plain and the continental shelf. The coastal plain shows two types of depositional systems formed from the Tertiary, associated to Quaternary sea level changes: (1) system of alluvial fans; (2) four different systems trangressive-regressive type lagoon-barriers, formed during the last 400 ka.

The continental shelf presents a shallow and flat morphology (MARTINS *et al.*, 1972), showing gradients in the order of 1:1000, with a dense paleo-drainage and many features associated to the subaereal exposure during the Pleistocene (MARTINS, 1999; CORRÊA, 1995, 1996). Asp (1999) detailed the morfo-structural analysis that gave evidence of the still steady sea level on the shelf and their correlatioship to mapped structures on the continent. FACHIN (1998) studied the shoreface and inner shelf dynamics on the southern coast of RS, revealing deficit in the sedimentary net and a morphological

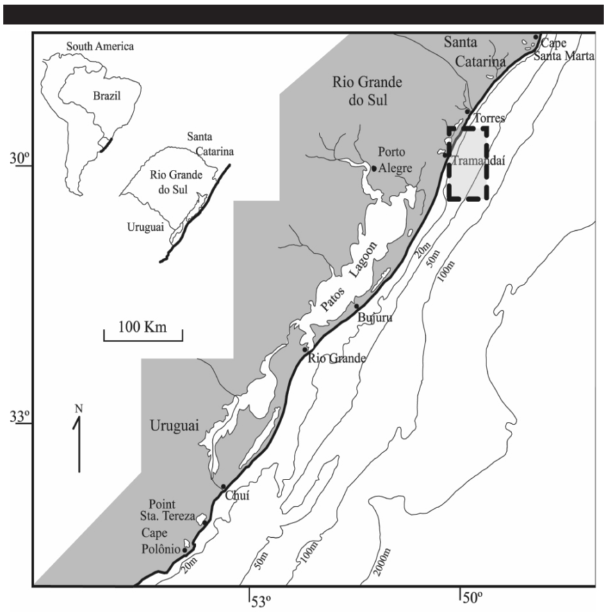

Figure 1. Geographical setting of study area on the northern coast of Rio Grande do Sul, Brazil.

controlling influence.

Coast erosion has been discussed by authors like CALLIARI *et al.* (1996,1998 2000) as resulting from wave and storm action. TOMAZELLI *et al.* (1996, 2000) characterize sections of progressive erosive processes, as a present answer to relative sea level variations. TOLDO JR. *et al.* (1999), identified some erosion tendencies and rates along the coast. DILLENBURG *et al.* (1998; 2000), consider different responses of the shoreface slopes and of its geological inheritance of holocenic barriers variability patterns along the RS coast.

MATERIAL AND METHODS

The analyses are based on 6 perpendicular and 8 longitudinal profiles off the coast, with 887 km of detailed bathymetric data and 770 km of side scan sonar surveys. Such data was correlated with a total of 278 sedimentary samples of the inner shelf, 55 samples of 11 shoreface profiles and of 90 sedimentological samples and fauna from 27 cores, collected from the depth 20 to 50 m.

Sonar and Bathymetric Data

The detailed analysis of the bathymetry survey operated with DGPS, echoes SIMRAD EA-500 and OCEAN DATES TDS-1000, in to acquire 8.000 points (tops) of positioning, on the inner shelf with depths from 20 m to 50 m. The 11 shoreface profiles, were done from the swash zone to 15 m and georeferenced with the coastline by TOLDO JR. *et al.* (1999), collecting 5 sedimentary samples for each profile.

The side scan sonar data was recorded and processed on the HYDRO/Qmips system. The digital integrated treatment of sonographic, echo bathymetry and DGPS/track-point for fish position corrections improved the performance of the data recording. These scans covered a 100 m strip from the depth of 20 m to 30 m of water, and another 200 m strip, from the depth 30 m to 50 m. FACHIN and. HOEFELL (1995), analyzing the bottom morphology mosaic and sedimentary data identified 12 songraphic groups.

Sedimentology, Cores and Fauna

The sedimentary samples were analyzed according the FOLK and WORD (1957) in fractions of ½ and processed by the Pancon software (TOLDO JR and MEDEIROS, 1984). This defined the textural classes as well as their statistical parameters.

For the analyses of the micro-fauna, 15 samples of 8 cores collected along the sections, were selected to characterize the .

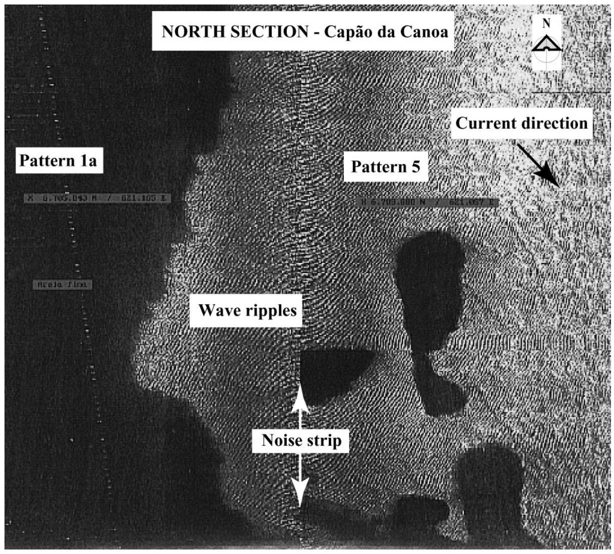

Figure 2. A side scan sonar record of high sonographic reflection patterns with wave marks on sands, like sheet of bioclastic gravel (pattern 5) displacing over sand and silty sand sediments (pattern 1a) of low sonographic response.

paleoenvironmental conditions and evolution of the shelf and shoreface. The bioclasts were studied in the fractions of >1.00 to 1.41 . Environmental behavior of the species were based on the literature considering: depth categories, substratum and salinity (Rios, 1994; REICHHART *et al.,* 2001).

RESULTS

The morphology aspects, given by the bathymetric and sonographic data, show at the inner shelf, quite a regular topography and low gradients. The database permitted the making of morphologic and sedimentary maps and block-diagrams with bathymetric and sedimentary distribution. Also, profiles from the shoreface to the inner shelf (40 m) were done. Correlationships with a large number of samples and cores permitted to detail local and regional variations of gradients, sedimentary distribution and the major features.

Based on this integrated data analyses (GRUBER and NICOLODI, 1998; GRUBER *et al.,* 2000; NICOLODI and GRUBER, 1998) 3 main sections of morfo-sedimentary distribution were defined: (a) North (b) Center (c) and South Section, all controlled by morfo-structural factors, possibly associated to the antecedent topography.

The **North Section** presents steeper gradients in the shoreface and lower gradients on the inner shelf. The sand contribution, from fine to very fine, on the shoreface, changed to coarse material on the inner shelf. This was also identified by high sonographic reflection patterns with wave marks on sands, bioclastic gravel and very localized calcareous outcrops (Figs. 2 and 3).

It was interrupted by localized low reflections that corresponded to mud. The limit of the shoreface-inner shelf is around 18 m of depth.

In a transition, the **Center Section** shows areas between positive and negative variations in the bathymetry below the 30 m of water. This is also reflected in the sedimentary distribution, like inherited behavior of the ancient topography and geological control, displayed by the high songraphic reflection patterns as well as in the sediments. Sedimentological analyses indicating the presence of muds in the negative bath areas, with sands and shells, were associated in positive areas. The toe of shoreface was between 16 to 20 m.

In the **South Section**, the slope is smooth but progressively deepens. The toe of shoreface is not clear in their limit with the inner shelf, varying from 16 m to 25 m. This showed an erosional shape design. Fine sediments compose the textural

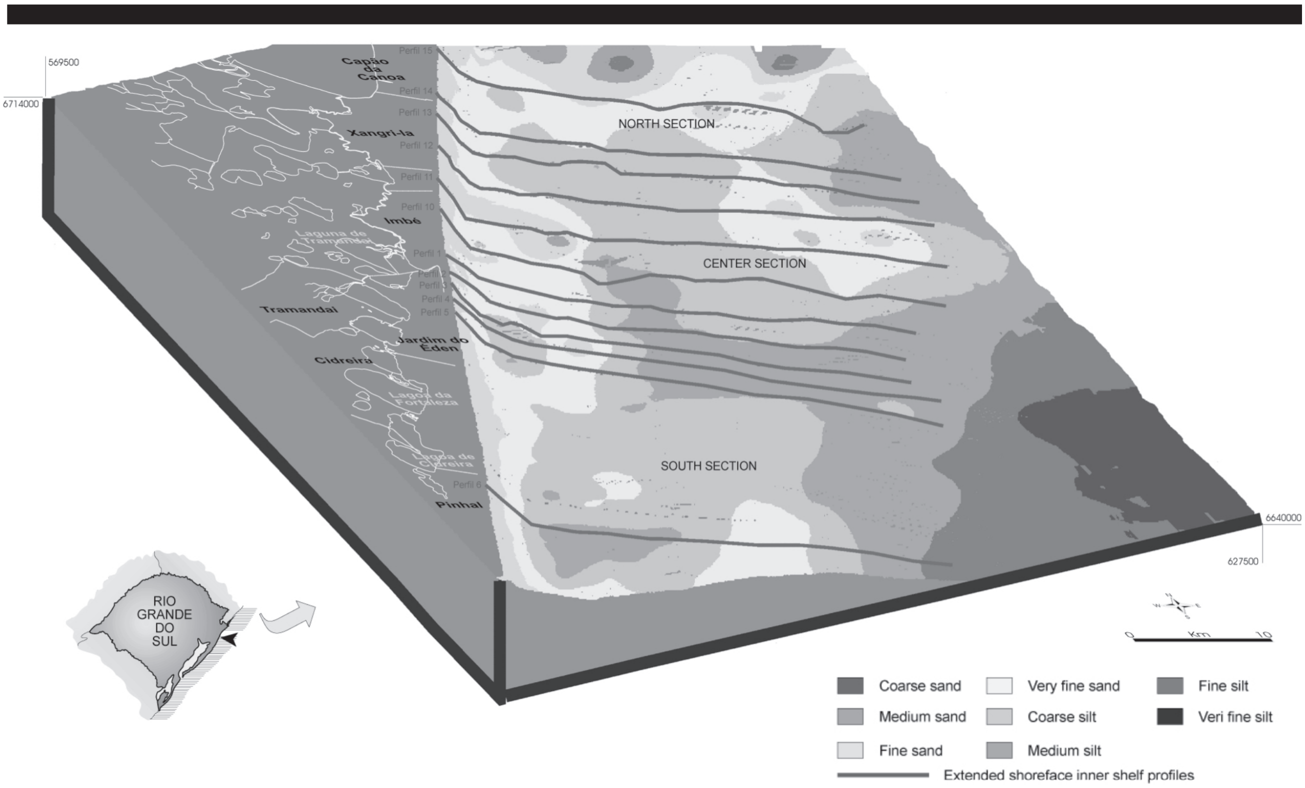

Figure 3. Block-diagram with morpho-sedimentary distribution and also the sectors of the studied area. Extended shoreface inner shelf profiles are plotted over, to detail these morpho-sedimentary contrasts, sediment sources and the shoreface toe setting.

cover, also given by the low songraphic answer patterns (Fig. 3).

Sonographic, textural and statistical parameter maps revealed eight main facies: coarse sand; medium sand; fine sand; very fine sand; coarse silt, medium silt and fine silt and very fine silt. Extend shoreface profiles, down to 40 m of water depth, characterized the shoreface-inner shelf morphodynamic boundaries (toe), at 18 m on the North section, changing to the Center section, from 16 to 20 m and to the South section, from 16 to 25 m water depth, with an erosional characteristic designs (Figure 3).

The sedimentological cores data confirmed these results. They were corroborated by the fauna found in the sections, composed dominantly by mollusks (bivalves, gastropods and scaphopodos), with the presence of equinoderma fragments, barnacles and briozoas.

The paleofauna of all of the analyzed samples is aloctone, being *Mactra sp*. (probably *Mactra petiti*) the most abundant. Small and young specimens are dominant. According to RIOS (1994), they could not reach adulthood. The small size individuals resulted from well sorted caused by winnowing processes and/or resulting from unfavorable environmental conditions.

The identified species are infratidal, shallow marine, with little tolerance of low salinities, characterizing environments of shallow open marine and (lagoonal) estuarine fauna.

DISCUSSION AND CONCLUSIONS

Limits of Shoreface-Innershelf Morphodynamics

According to NIEDORODA *et al.* (1984) and WRIGTH *et al.* (1991), the modern modeling processes of cross shore transport consider that the movement of sand through the shoreface preserves the dynamics printed by waves in the sediments. Roy and COWELL (1991) discuss the effects in the mobility and in the reworking of those sediments on the shoreface-inner shelf interface, generated under storm conditions. For these authors, the reworking of beach erosion mechanisms, especially during storms surges, influences the sedimentary texture.

For WRIGHT *et al.* (1991) field measurements revealed that the sediment flows magnitude are larger, during storms than during fair weather periods, when dominated by waves action. Such conditions can be shown in the study area, based on the side scan sonar records with the textural distribution and core analysis.

The records showed a displacement of great bioclastic gravel and sand sheets, with ripples at 26 m of water depth, mobilized by basal currents over siltysand sediments, in the lower shoreface and inner shelf (Figure 3).

It was also possible to indicate the external limits of the dynamics of the shoreface and inner shelf (NIEDORODA *et al.*, 1984; ROY and COWELL, 1991; SHORT 1984, SHORT and HESP, 1982, STIVE and DE VRIEND, 1995). This occurs in strip located among the isobaths 15 m / 25 m, with variations and in different sections. Also, promoting the discussion of sedimentary supply and the morfodynamic aspects (Fig. 2).

Results of integrated data from side scan sonar, morphology, surface sedimentary distribution, core and paleofauna analysis indicate that the morfo-sedimentary distribution pattern reveals a morfo-structural and geological inheritance correlationships in the area.

These were partially preserved, even after the sea level rise. Such distribution configures accumulations of modern deposits, in contrast to relict sediments, and palimpsests, partially reworked by winnowing.

The analyzed paleofauna indicates shallow open sea or barrier island environments. These resemble results taken from holocenic barrier cores by DILLENBURG (2000), that characterized a nearshore open sea fauna, and also correlated with results of back-barrier cores obtained along the coast by REICHHART *et al.* (2001).

The morpho-sedimentary distribution and stratigraphic data, from the cores, indicate the evolution processes of the barrier translation of beach and shoreface over past marine, back-barrier and lagoon environments.

It explains some sedimentary variations of relict and palimpsest sediment occurrences and even some aspects of the antecedent topographical conditioning that could be associated to the translation of coastlines and at past steady sea levels.

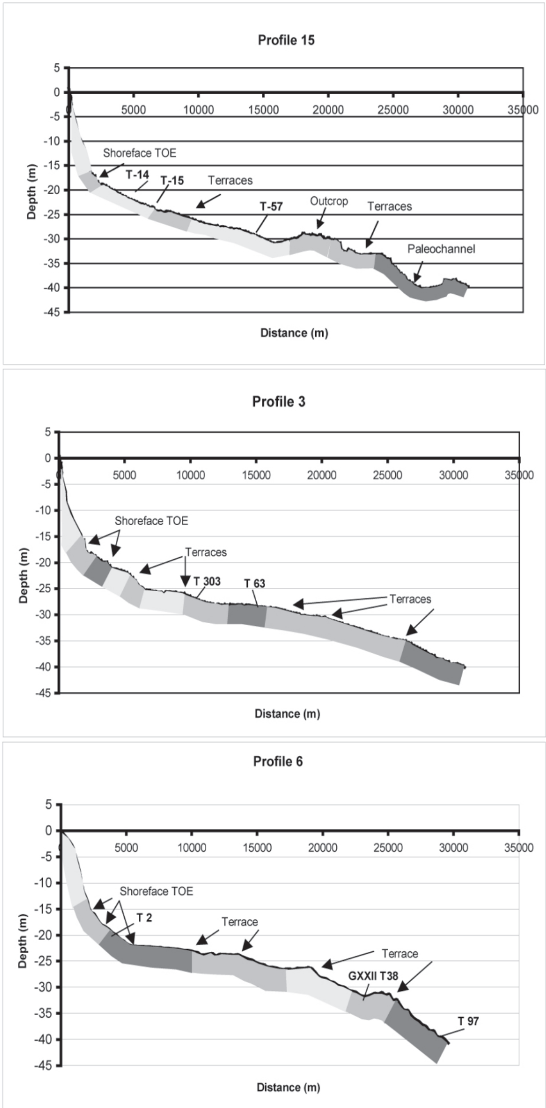

Figure 4. An example of a figure considered to one column. (The caption of a figure should be in Times New Roman 9 font)

Sedimentary Supply Sources

The sedimentary supply source analysis, based on the distribution maps and core content, makes it possible to indicate some areas and their sediment contributions.

The contrasting sections with bioclastic fraction occurrences, in the lower shoreface and inner shelf, contrasts with other areas, which are associated to fine sediments. These occurrences seem to be an inheritance from specific inner shelf areas, that were reworked into gravel sheets and bioclastic sands, as well as muddy deposits winnowed by bottom currents ROY *et al*., (1995) suggest two sources: (1) present fine sediment lagoon supply, reworked beach sand, of the supply of beach sand and holocenic shoreface and available Pleistocene; (2) reworks of ancient deposits of lower shoreface and inner shelf associated the (a) shelly deposits of old beach lines and (b) muddy deposits of lagoon of pleistocenic back barrier.

CONCLUSIONS

The characteristics observed in the shoreface in the RS are configured by the interaction of the sea dynamics and of the morphology of the shelf, reproduced in the sedimentary distribution and bottom features. It contemplates in its morphology, the influence of the geological inheritance as a antecedent substratum control, contemplated in the evolution features in the coastline translation during Holocene.

The morphologic maps of detail presented 3 main sections controlled by morfo-structural factors: North Section, Setor Center and South Section. The external morphologic limit of the dynamics of the shoreface it was very defined to 18 m for the North Section, leveling for an indefinite area of break among 16 to 25 m for the Center Section.

Cores and fauna data revealed a correlationship of the morfo-structural conditioning and geological inheritance of the area, over its evolution and paleogeographic environments.

Such process would have been responsible for the sedimentary variations sources as well as the relic and palimpsest in the coastline translation during the Holcene transgress ion.The shoreface-inner shelf profiles behavior and morphologic limits contrasts, also with the geological inheritance reinforces the holocenic barriers model variability proposed by Dillenburg *et al.* (2000) to the Rio Grande do Sul northern coast.

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