LATE QUATERNARY GEOLOGICAL HISTORY OF RIO GRANDE DO SUL COASTAL PLAIN, SOUTHERN BRAZIL

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ABSTRACT The sedimentary deposits and geomorphic features preserved in the Rio Grande do Sul coastal plain, southern Brazil, represent a significant record of late Quaternary climatic changes with its associated glacio-eustatic sea-level fluctuations. The sediments of the coastal plain belong to two major depositional systems - an alluvial fan system developed along the inner part of the coastal plain and a barrier-lagoon complex with four distinctive transgressive-regressive cycles seaward. The alluvial fan sediments were derived from igneous and metamorphic rocks of the Precambrian shield and from sedimentary and volcanic rocks of the Paraná Basin. Subsequently, they were reworked by four barrier-lagoon systems each representing a transgressive-regressive cycle. Each barrier probably originated at the landward limit of a transgression and was preserved due to regression of the shoreline forced by a glacio-eustatic sea-level fall. The four barrier-lagoon systems are believed to have formed during the last 400 ka assuming a correlation with the highstands represented by the last major peaks of the oxygen isotopic record.

Keywords: Quaternary geology, sea-level variations, coastal evolution, Rio Grande do Sul coastal plain

INTRODUCTION The Rio Grande do Sul coastal plain is an elongate (620 km) and wide (up to 100 km) physiographic province underlain by the Pelotas Basin. This basin, the southernmost of the Brazilian continental margin, has accumulated more than 10,000 m of mainly terrigenous sediments since its formation in the Early Cretaceous, when the South Atlantic began opening. The younger section of this sedimentary record is now exposed on the Rio Grande do Sul coastal plain and contains one of the most complete records of Brazilian coastal Quaternary sedimentation (Fig. 1).

This paper summarizes knowledge about Rio Grande do Sul coastal plain sediments and suggests an evolutionary model for them during the Quaternary.

PHYSICAL AND GEOLOGICAL SETTING OF THE STUDY AREA The coastal plain of Rio Grande do Sul has a nearly straight shoreline between about 29º S and 34º S latitude. Covering an area of about 33,000 km^2, this large lowland embraces a great number of coastal water bodies, some of them of large dimensions, such as the Patos Lagoon with an area of 10,000 km^2 and Mirim Lagoon with an area of 3,770 km^2.

At the northern end of the coastal plain the adjacent highlands consist of Paleozoic and Mesozoic sedimentary and volcanic rocks of the Paraná Basin that locally reach 1,000 m. At the southern section, igneous and metamorphic rocks of the Precambrian shield form lower highlands. At present, all sandy sediments eroded from these highlands and transported by rivers to the coast are trapped in the coastal lagoons and other backbarrier environments and none reaches the oceanic shoreline.

The climate of the region is temperate, humid, with an even distribution of rain throughout the year, averaging around 1300 mm.

The coastal plain is dominated by a bimodal high-energy wind regime. The dominant wind comes from NE and is more active in spring and summer months. The secondary W-SW wind becomes more important in the autumn-winter months. The coast of Rio Grande do Sul is a wave-dominated microtidal coast with semidiurnal tides with a mean range of about 0.5 m. The region is affected by swell waves approaching from SE that produce a net northerly alongshore transport of sediment. Besides the swell action, sea waves from E and NE and episodic storm waves from E and SE control erosional and depositional processes along the seashore.

The adjacent continental shelf has an average width of 150 km and the shelf break is situated at a depth of about 170 m. Bottom sediments on the shelf are predominantly terrigenous clastics with some biodetrital concentrations that seems to be mostly relic.

COASTAL PLAIN DEPOSITIONAL SYSTEMS **Alluvial fan system** This system includes facies formed through sediment gravity flows and alluvial processes along the inner part of the coastal plain. The sediments consist of mass flow deposits in proximal regions (mainly massive debris flow and colluvial slide deposits) grading seaward into waterlaid facies associated to braided channels with cross-stratified sandy and gravelly deposits. The composition and texture of the alluvial fan facies mainly reflects the nature (relief and composition) of their primary source area. To the north, the facies derived from high relief volcanic and sedimentary rocks of Paraná Basin are coarser and have a lithic composition. To the south, where the Precambrian shield is mainly formed by granitic rocks, the lithofacies are finer and have an arkosic composition.

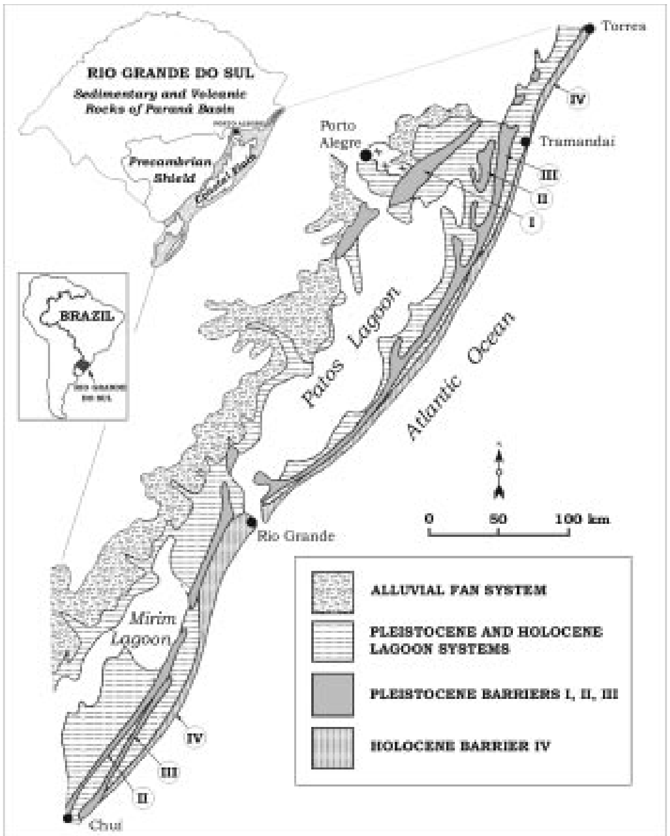

Figure 1–Location and simplified geologic map of Rio Grande do Sul coastal plain (Modified from Tomazelli and Villwock 1996).

In general, the alluvial fan facies are texturally and mineralogically immature and include gravels, sands and mud forming individual bodies with lenticular geometry. The oxidizing conditions of the depositional environment imprinted a widespread reddish color to the sediments with local concentrations of iron oxides and hydroxides forming concretions, crusts and limonitic enriched beds. Many clasts are deeply weathered. In some places the fine-grained alluvial fan facies display large circular burrows, up to 1 m of diameter, interpreted as ichnofossils of Pleistocene mammals (Bergqvist and Maciel 1994).

The deposition of the alluvial fan system had probably already began in the Tertiary (late Pliocene regression) and continued during all the Quaternary with an intensity controlled by cyclic changes from

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humid to arid conditions that occurred during this time. Variations in rainfall and in development of vegetation cover have profoundly affected the fan system. Probably, the most important depositional events occurred during arid periods, when vegetation cover was restricted favoring the occurrence of episodic debris flow processes. During humid periods the morphology of fans was modified by action of more perennial, normal streams and other superficial secondary processes such as gulling and soil formation. As a result, the classical semi conical shape of individual fans was lost and replaced by an almost continuous alluvial apron that dips gently seaward. This ramp morphology was a product of coalescence of adjacent fans and also the result of subsequent erosion and reworking, including the formation of terraces by marine and lagoonal waters operating on fans toes during sea-level highstands when the system was a fan-delta.

From a geometric point of view the alluvial fan depositional system corresponds to a clastic wedge that thickens toward the interior of the Pelotas Basin. A thickness of 270 m of alluvial fan sediments was revealed in the PETROBRAS well 2-MO-1-RS located close to the present shoreline (Delaney 1965).

At present, the facies of alluvial fan system occur all over the western strip of the coastal plain adjacent to the highlands (Fig 1) and especially to the south of the region where the alluvial fan apron surface has a succession of terraces formed by marine and lagoonal processes during the several Pleistocene transgressive events.

Barrier-lagoon systems Quaternary glacio-eustatic fluctuations in sea level produced great lateral displacements of the shoreline on the very low gradient of Rio Grande do Sul coastal plain and continental shelf. Consequently, four barrier-lagoon systems were formed and preserved landward of the present coastline.

PLEISTOCENE BARRIER-LAGOON SYSTEMS Three barrier-lagoon systems of Pleistocene age were identified on the coastal plain (Villwock *et al* 1986) and from oldest to the youngest are called I, II and III, respectively (Fig. 2).

The Barrier I is the inner, and consequently, older depositional system formed as a product of the first locally recognizable Pleistocene transgressive-regressive event. This system is best developed in the northwestern part of the coastal plain where Barrier I appears today as a NE-SW strip about 250 km long and 5 to 10 km wide. Here the barrier grew mainly by aeolian sands onlapping basement highs.

Barrier II was formed during the second local Pleistocene transgressive-regressive cycle and sediments are best preserved in the southern portion of the coastal plain, where they were responsible for the initial formation of Mirim Lagoon (Fig. 1).

Barriers I and II are composed mainly of well-rounded, fine to medium grained, reddish-yellow, semi-consolidated quartzose sands

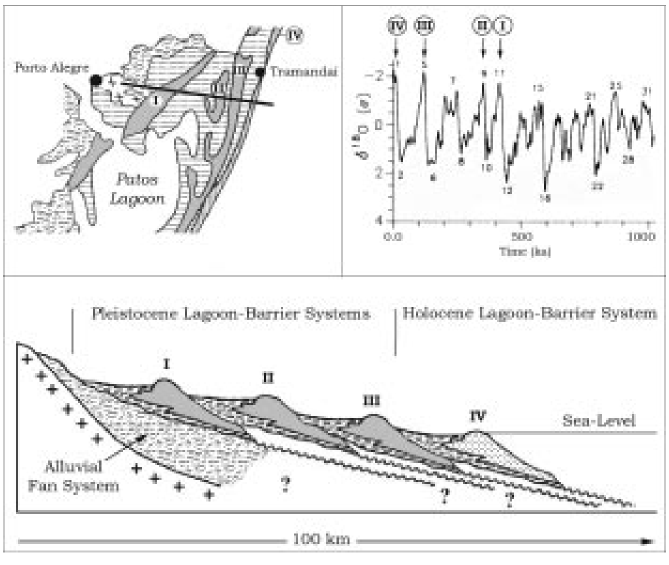

Figure 2–Generalized section of depositional systems across the coastal plain of Rio Grande do Sul. Barriers are correlated with the last peaks of oxygen isotopic curve (Williams et al 1988 – Fig 14). See Fig.1 for location and captions.

with up to 15 % of silt-clayey matrix. The origin of this matrix is clearly pedogenic, resulting mainly from chemical breakdown of feldspars and other minerals in the soil profile followed by process of clay illuviation. In most outcrops the facies appear completely massive because pedogenic processes have largely destroyed the primary sedimentary structures. In some places the Barrier I sediments have root traces and their concentration in distinct levels suggests palaeosoils. During phases of humid climate, the Barrier I coastal dunes was stabilized by vegetation while during arid phases vegetation cover was largely destroyed and aeolian activity resumed.

Barrier III is the best preserved of the Pleistocene barrier systems. Its correlative sediments can be traced from north to south along the whole of the coastal plain and its development is clearly responsible for the final formation of the large Patos and Mirim lagoons (Fig. 1). The vertical facies succession of Barrier III testifies to its regressive stratigraphic nature. The barrier is composed by sandy beach facies covered by aeolian deposits. Beach facies consists of white, well sorted, quartzose fine sand, with very well developed stratification reflecting different process occurring in the various beach subenvironments. Aeolian facies are composed of reddish, quartzose, and structureless fine sand with abundant root traces. Locally, the beach sands contain remarkable occurrences of *Callichirus* sp. burrows. The level of highest concentration of *Callichirus* burrows defines an ancient sea-level situated around 6-8 m above the present.

Lagoonal Systems I, II and III all developed at the backbarrier setting between the mainland and the equivalent Pleistocene barrier systems. The deposits accumulated in these environments are represented mainly by cream colored, poorly selected, silt-clayey sands, either massive or showing parallel lamination, and have calcareous and ferruginous pedogenic concretions. In some places the pedogenic concretions are highly concentrated and form carbonate-rich layers up to 1 m thick, probably reflecting significant semi-arid paleoclimates. Pleistocene mammal fossils have been found associated with these lagoonal deposits, especially in the southern part of the coastal plain (Paula Couto 1953).

HOLOCENE BARRIER-LAGOON SYSTEM The most recent barrier-lagoon system of Rio Grande do Sul coastal plain (Barrier-Lagoon IV) has been developed during the Holocene. At the final stages of the Post-Glacial Marine Transgression (PMT), when sea level was rising under low rates, coastal evolution was strongly influenced by antecedent topography. Not only has this earlier topography played an important role in the definition of the coastal shape at the maximum of the PMT (5 ka), but it has also pre-determined the type of coastal barriers that formed. Here the barriers have been subjected, over the long term, to two contrasting coastal processes: deposition in coastal bights leading to the formation of prograded barriers, and erosion along protruding stretches of coast leading to the formation of transgressive dunes, receded barriers and mainland beach barriers (Dillenburg *et al* 2000). The Holocene barriers have beach sands that are quartzose, fine to very fine grained and show, in certain places, high concentrations of heavy minerals. The dune field is well developed along protruding stretches of the coast with a variable width of 2 to 8 km. In response to the action of the NE dominant wind, the dunes are mainly barchanoid ridges and actively transgress the hinterland in a SW direction.

The Holocene Lagoonal System has been developed in the backbarrier region between the Barrier IV and the mainland consisting of Pleistocene Barrier III. At the peak of the PMT, at about 5 ka, large lagoons, which have partly evolved to other environments such as lakes, swamps and floodplains, occupied this region. Moreover, during the Holocene highstand the flooding of the lowland situated between the Pleistocene barriers and the alluvial fan apron has re-established and widened the Patos and Mirim lagoonal bodies (Fig. 1).

Fine to very fine sands, mud and peat deposits are the main sediments that accumulated in the complex depositional sub environments of the Holocene Lagoonal System.

GEOLOGICAL EVOLUTION OF THE COASTAL PLAIN

The interpretation of the Holocene system below is based on more than forty cores and approximately ten drill holes, plus thirty radiocarbon datings. Because of an absence of subsurface data most of our knowledge of the Pleistocene systems is based on surface sedimentologic and geomorphologic information plus geological reasoning.

Geological reconstruction begins with the development of a gently eastward-dipping, seaward-thickening sedimentary wedge of coarse-grained terrigenous clastic sediments accumulating as an alluvial fan/ fan delta system. The upper and proximal section of these deposits outcrops, today, along the inner part of the coastal plain. In subsurface these alluvial deposits overlie Miocene marine beds, which suggests that this alluvial fan system attained its highest degree of development during the late Pliocene and lower Pleistocene regression, when the semi arid landscape of the coastal plain consisted of a wide ramp gently dipping toward the sea.

During the Quaternary, the distal and uppermost portions of the alluvial fan deposits were reworked during at least four major transgressive-regressive episodes, which were responsible for the construction of four barrier-lagoon depositional sequences.

Due to lack of suitable materials for reliable dating, absolute ages of Pleistocene sequences are still uncertain, especially for the oldest ones (Barrier I and II). But, considering that glacio-eustasy was the prime factor controlling sea level fluctuations during the Quaternary, it is reasonable to correlate the barrier-lagoon systems of Rio Grande do Sul coastal plain with the last major peaks on the oxygen isotopic record (Williams *et al* 1988). Consequently, based on the limited data available to date, it seems likely that these systems were formed during the last 400 ka (Villwock and Tomazelli 1995).

The first and second transgressive-regressive cycles, responsible for construction of Barrier-Lagoon Systems I and II, are tentatively correlated with oxygen isotopic stages 11 (around 400 ka) and 9 (approximately 325 ka), respectively. The third cycle, responsible for formation of the long, wide and fairly well preserved Barrier III is correlated with oxygen isotopic sub stage 5e, approximately 125 ka. Barrier III deposits, originated near the peak of the last interglacial transgression, can be firmly correlated with similar sediments founded in many other segments of the Brazilian coast (Suguio *et al* 1985).

Finally, the fourth and latest interglacial sea-level event, responsible for construction of the most recent barrier-lagoon system of Rio Grande do Sul coastal plain developed during the Holocene, corresponds to the ongoing oxygen isotopic stage 1. The history of this last cycle is very similar to that revealed by studies along other segments of the Brazilian coast (Suguio *et al* 1985). Beginning at about 18 ka, when sea-level at the maximum lowstand was near the shelf break, the last PMT moved the shoreline across the subaerially exposed continental shelf until the maximum flooding was attained, around 5 ka. At this peak, sea level was 2-4 m above the present level. During the subsequent fall there was a rapid progradation of Barrier IV along coastal bights. Along coastal projections, any potential for progradation induced by the sea level fall after 5 ka was overwhelmed by erosion, probably associated with both the focusing and higher wave energy on protruding (steeper) sections of the coast. At the same time fine-grained sediments, supplied by rivers, promoted a general aggradation in the lagoons and other depositional backbarrier environments. Because the beach received no coarse-grained sediment from rivers, it is probable that the sand supply for the progradation of Barrier IV came mainly from the inner continental shelf, as suggested by Dominguez *et al* (1987) for regressive Holocene sediments of the east-southeast Brazilian coast (Tomazelli *et al* 1998).

CONCLUSIONS The coastal plain of Rio Grande do Sul has four clearly defined Quaternary barrier-lagoon systems. Each system was produced in the course of an interglacial high sea level, probably during the last 400 ka. Other Quaternary high sea-levels identified in the deep-sea sedimentary oxygen isotope record do not seem to be present along the coastal plain or, if so, their deposits were buried or not preserved.

Although subsurface stratigraphic data are limited, there is evidence that each barrier system originated at the peak of a highstand so that its present position on the coastal plain marks the landward limit of the corresponding transgressive event. During the highstand and subsequent fall in sea level, the barriers prograded seaward. This dominant regressive phase is readily apparent in the vertical facies succession of Barrier III, and along coastal bights in the Holocene Barrier IV. Due to the virtual absence of large fluvial systems supplying sand to the beach, it is probable that the ultimate main source of sediments for shoreline progradation was the reworking of inner-shelf deposits, as a consequence of sea level fall or even during sea level stillstands.

The geological history of Rio Grande do Sul coastal plain is a good example of how barrier-lagoon systems in wave-dominated setting may be developed and preserved during transgressive-regressive cycles of high frequency controlled by glacio-eustatic sea-level fluctuations.

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