CHARACTERIZATON OF AN ANALOGOUS RESERVOIR: THE EXAMPLE OF HOLOCENIC COASTAL SAND BARRIER IN RIO GRANDE DO SUL, SOUTHERN BRAZIL

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Abstract – Coastal sand barrier systems can constitute excellent reservoirs of oil, gas and water. Good examples of these reservoirs, presently producing oil and gas, are found on sedimentary rocks in the western region of U.S.A. and Canada. At the Coastal Plain of Rio Grande do Sul (RS) State in southern Brazil, four systems of coastal barriers, juxtaposed laterally and showing different Quaternary ages were identified. This study focus on the analysis of the potential as an analogous reservoir of the youngest of these barriers, formed during the Holocene and known as Barrier IV. The study area is located nearby Cassino beach, where barrier IV is larger than any other place along the coast of RS. The techniques employed on the research are: fotointerpretation, geological mapping, drilling, granulometric analysis, radiocarbon dating and vertical eletric souding. The interpretation of the obtained data made possible the establishment of an evolutionary model for the Holocenic Barrier (Barrier IV). This model has a great importance on the characterization of the barrier as a reservoir. The stratigraphic package of the barrier is composed by a succession of offshore, shoreface, foreshore and aeolian deposits. These data allowed the classification of the barrier as a typically prograded one, developed under a forced accretionary regression. The identification in the reservoir of heterogeneities on macroscopic and megascopic scales has permitted the recognition of tree flow units.

Keywords: Analogous Reservoir, Coastal Barriers, Barriers Evolution

1. Introduction

Sand deposits of barriers show good porosity and permeability, which are properties that characterize good reservoirs of oil, gas and water. Adjacent fine sediments environments such as lagoons and middle to outer shelf are commonly good potential seal and source of hydrocarbons.

Another fact that calls attention for the high potential of coastal barriers as reservoirs is their favorable geometry in the form of thick (5 to 15 m), wide (1 to 5 km) and elongated (10 to 100 km) sand bodies.

Good examples of such reservoirs are found in cretaceous sediments in the Rocky Montains region, west of USA and Canada (*e.g.* Campbell, 1971; Cotter, 1975; Davies *et al.* 1975; McCubbin, 1982; Reison, 1984; Friedman *et al.*, 1992; Willis & Moslow, 1994; Selley, 1996), in Lower Silurian Sequences of Contry of Wales (Bridges, 1996) and in Rio Bonito Formation (Permian of Parana Basin), Brazil (Holz *et al.*, 2002).

Few examples making comparisons between modern reservoirs and their analogous in the geologic record are found in the in literature. Pryor (1973) made comparisons of permeability and porosity patterns between Holocenic and ancient deposits, pointing out to the importance of such compared studies.

The Rio Grande do Sul Coastal Plain (RSCP) was generally formed in the Quaternary by the lateral juxtaposition of sedimentary deposits of four barrier-lagoon systems, and therefore represents an excellent site for studies of reservoirs formed by paralic systems

This work is restricted to the characterization, as a reservoir, of the Holocenic barrier (locally called Barrier IV), in the Cassino region, located in the southern sector of the Rio Grande do Sul coast (Fig. 1). Following it will be presented the evolutionary model of the barrier based in Clerot (2004), and the reservoir heterogeneities and flow units based in the classification proposed by Galloway and Hobday (1996).

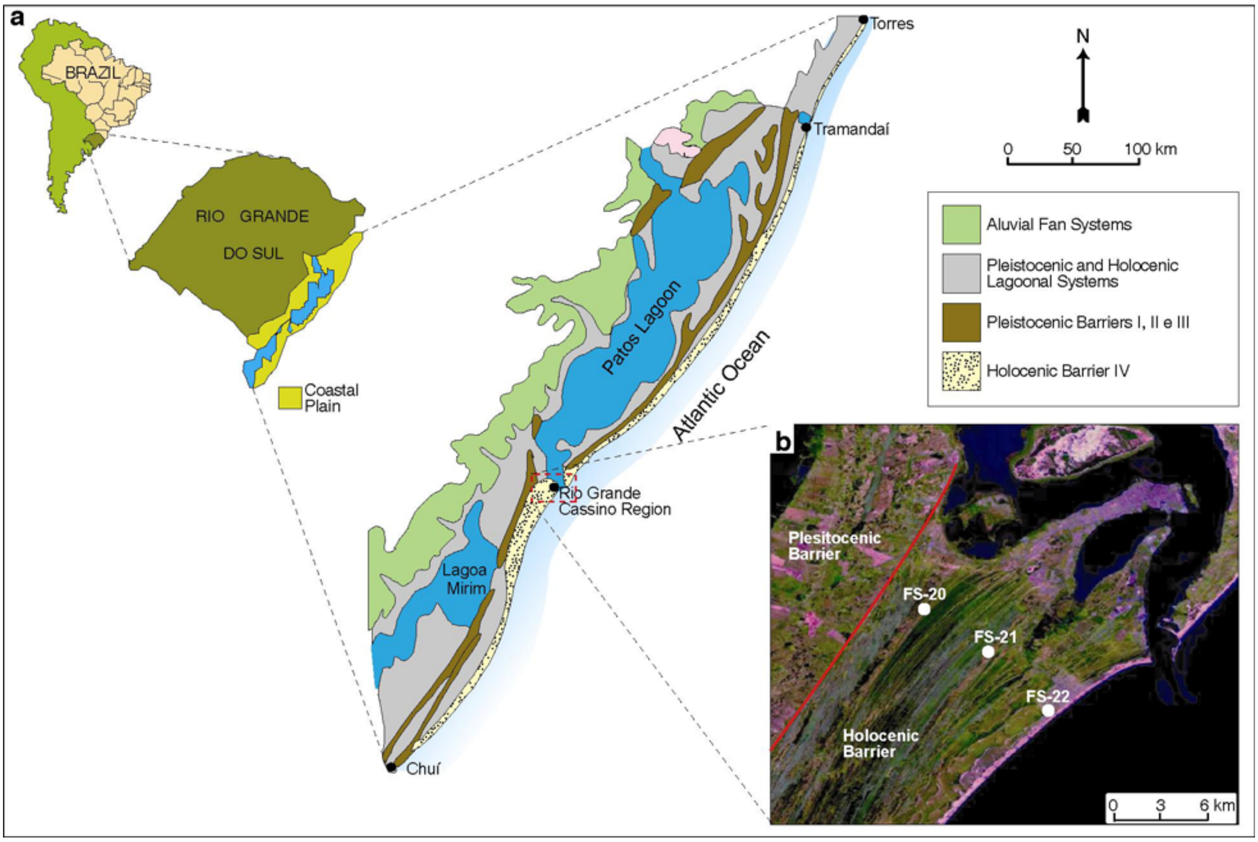

Figure 1 – (a) Location and simplified geologic map of Rio Grande do Sul Coastal Plain (modified from Tomazelli *et al.* 2000) and (b) Orbital image from Cassino region with the location of drillings FS-20, FS-21 and FS-22 (extracted from Embrapa).

2. Regional Setting

The RSCP represents the continental portion of the Pelotas Basin, which is the southernmost marginal basin of the Brazilian continental margin.

According to Villwock and Tomazelli (1995), four systems of coastal barriers, juxtaposed laterally and showing different Quaternary ages, are found in this geologic context. The systems I, II and III have pleistocenic ages, and system IV is Holocene in age. These systems were developed as a consequence of transgressive-regressive events, basically controled by glacio-eustatic sea-level oscillations related with Milankovitch Cicles.

The developement of Barrier IV is directly related to the Postglacial Marine Transgression (PMT) started at 17.5 ka when the sea level was about 120 m lower than present. Since that time sea level rose in an average rate of 1.2 cm/yr. Barrier IV is 620 km long, showing two discontinuities only: at the inlets of Tramandaí Lagoon and Patos Lagoon (Fig. 1a). In Cassino, Barrier IV is wider (14 km) than any other place along de coast of RS.

3. Methods

This study is primaly based on photointerpretation (1:60.000 and 1:110.000), geological mapping, drilling, granulometric analysis, radiocarbon dating and vertical electric souding. The geological mapping has consisted on the recognition and description of the regional geology, with more specific detailed studies in key outcrops. The 3 drillings were performed by a percussion system, with samples collected in depth intervals of 1 m. A total of 58 samples were analyzed with enphasis on granulometric properties and color. A gastrophod (*Olivanicillária sp.)*, colected in drilling

FS-20 in a depth of 23.0 m, was dated by ^{14}C at Beta Analytic Inc., Miami, Florida, USA (Sample Beta – 185453). Eight vertical electric resistivity soundings were carried out under a Schlumberger configuration. The obtained data was processed in the Resist 87 software.

4. Geology and Evolution of Barrier IV

The stratigraphy of the barrier at Cassino is characterized by a vertical succession of basal transgressive sands, offshore, shoreface, foreshore and aeolian deposits. In a simple analisys these deposits could be grouped in two phases: a transgressive and a regressive phase. The first corresponds to the final stages of the PMT, when barrier migrating landwards has leaved a “tail” of basal transgressive sands. Although the drillings did not reach this layer, the electric resistivity data made possible the interpretation of these basal deposits as composed of fine to very fine sand with some clay. The offshore deposits have started to form still in this phase. At the maximum of the PMT (5-6 ka), with sea level positioned at approximately 3.5 meters, the first sediments of the barrier started to be deposited. The second phase (regressive) has started after the maximum of the PMT, when sea level started to fall very slowly until its present position .Although this fall has operated in a higher frequency than the PMT, it was interpreted as a regressive phase. The offshore sediments were formed continuously during barrier progradation. They were progressively recovered by shoreface, foreshore and backshore (aeolian) deposits. This offshore facies is composed of a dark gray to black, mud and sandy mud, with micaceous and glauconitic minerals and shell fragments. According to Clerot (2004), micropaleontological data indicates a decrease in marine conditions from the base to top of this facies, what would be expected in regressive phase sedimentation (Fig. 2).

Overlaying the offshore facies, a continuous layer of shoreface sediments, (8,0 m to 9,0 m thickness) occurs. The lower and intermediate shoreface is characterized by a greenish gray, very Fine (50 to 90%) to fine (5 to 40%) quartz sand, moderately sorted, with micaceous and glauconitic minerals and fragments of shells. This facies shows an increase in grain size to the top. The upper shoreface is composed of a greenish gray, fine (50 to 65%) to very fine (±30%) quartz sand, well to moderately sorted. This facies is very similar to the foreshore facies. In drilling FS-20 (12 km landwards from the present shoreline), at a depth of 23.0 m, one and well preserved shell of *Olivanicillaria* sp. was dated on 4.940 ± 80 yr (^{14}C).

These data allow to state that Barrier IV, in the study area, was mainly developed during the Holocenic Regression, under an accretionary forced regression. This statement is evidenced by the high rate of sediment input to the coastal system that resulted in an average rate of progradation of 2,45 m/year. These data are presented in Table 1.

The foreshore deposits recover the shoreface sediments, and shows an average thickness of 2,5 m. It is composed of gray to pale greenish gray, fine (>75%) and very fine (±25%) quartz sand and well sorted. This facies commonly shows a swash cross stratification.

Over the foreshore sediments a small aeolian layer occurs, varying from 0,5 m to 2,5 m in thickness, composed of yellow to brownish yellow, fine and well sorted quartz sand. This facies is related to foredune ridges and some transgressive dunefields. Its granulometric characteristics are very similar to the foreshore and upper shoreface facies.

Based on both air photographs and field data, six sets of foredune ridges were identified at the barrier surface. These sets of foredune ridges were individualized according to ridges orientation. Their changes on orientation reflect realignments of the coast during the regression phase, probably in response to climatic changes affecting the wave climate.

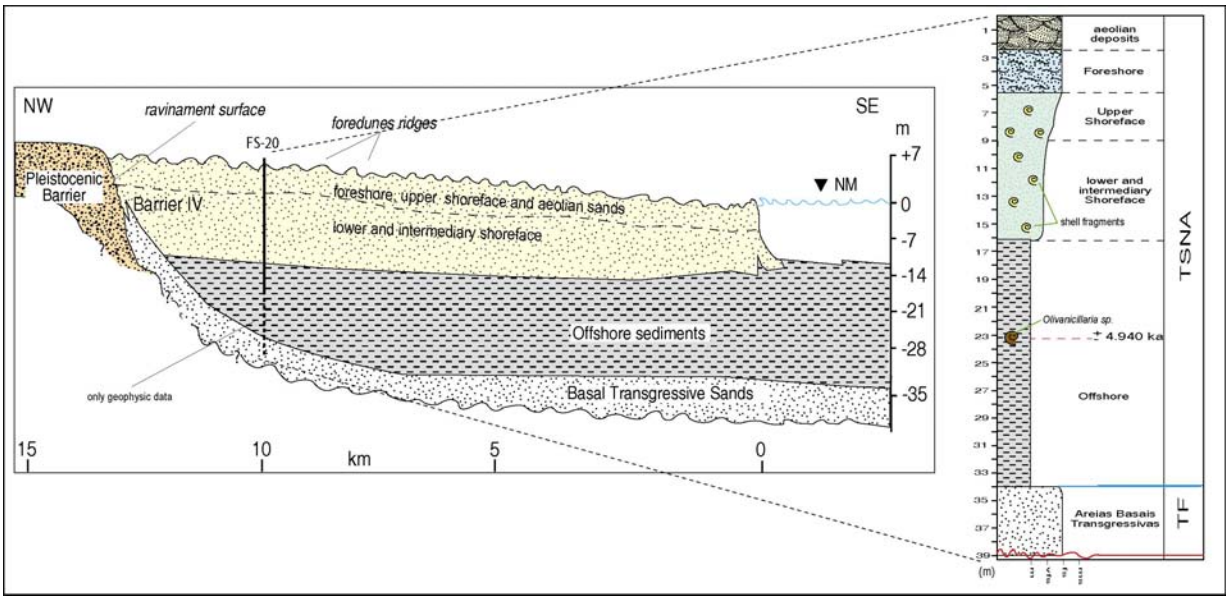

Figure 2 –Geologic profile across the Barrier IV in Cassino region.

Table 1 – ^{14}C ages, time interval, sea-level altitude and rate of progradation.

Conventional age (14C yr BP)	Time interval	Distance form the actual shoreline	Beach facies altitude (m)	Estimated sea-level altitude (m)	Rate of progradation (m/year)
4.940 ± 80	**4,9 ka a 0**	**12 km**	**+ 4,5**	**+3,5**	**2,43**

5. Characterization as an Analogous Reservoir

The most important aspects of reservoirs are the limits with the adjacent units and internal proprieties of sand bodies. The limits of the sand body with the adjacent units are very important points in reservoir characterization, therefore they become important to identify, in addition to the geometry of the body, its limits and contact forms. The physical discontinuities, like erosional surface, are a favorable place for fluid flow and precipitation of minerals. These surfaces can represent a potential barrier to the hydro-carbons or water migration.

As mentioned previously, Barrier IV is approximately 618 km long, parallel to the RS coast, and therefore it represents an expressive volume of sediments. The area encompassed in this work comprises a portion of barrier situated immediately to the south of the Patos Lagoon inlet, with 10 km in length along the coast. In this region the barrier has about 14 km of average width, limited by the Pleistocenic Barrier at the NW and the Atlantic Ocean at the SE (Fig. 1).

The Pleistocenic and Holocenic Barriers are two independent flow units, compartmented by a ravinement surface, defined at a megascopic scale according to Galloway and Hobday (1996), as they correspondent to two individual depositional systems (Fig. 3).

As observed in the drilling profiles and the vertical electrical sounding, the identified layers of Barrier IV present a good lateral continuity, with a small variation in thickness in the transversal direction. In the drilling FS-20 the sand layers (aeolian deposits, foreshore and shoreface deposits) present a thickness of approximately 17,0 m, with 16,0 m and 14,0 m in drillings FS-21 and FS-22, respectively.

According with Pryor (1973), permeability and porosity are important characteristics of sand-reservoir bodies, their magnitudes, patterns, and variability significantly influence the migration, accumulation, and distribution of fluids in the reservoirs. As the permeability of a sand body decreases proportionally to the grain size, there is a possible decrease in permeability within the same sand body as grain size decreases from proximal to distal facies associations.

In general, the facies identified in Barrier IV can be grouped in two facies associations with similar grain size. The first facies associations is composed of aeolian, foreshore and upper shoreface sediments, with predomination of fine-grain sand, and the second facies association is composed of intermediary and lower shoreface sediments, with predomination of very fine-grain sand.

So we can define a heterogeneity determined by changes in grain size of sediments. Probably this heterogeneity corresponds to a heterogeneity at macroscopic scale, where the flow units are defined by internal properties of sand body. In this way, it's possible to separate one flow unit (FU-1) composed of intermediary and lower shoreface from another flow unit (FU-2) composed of upper shoreface, foreshore and aeolian sediments, both in Barrier IV (Fig. 3).

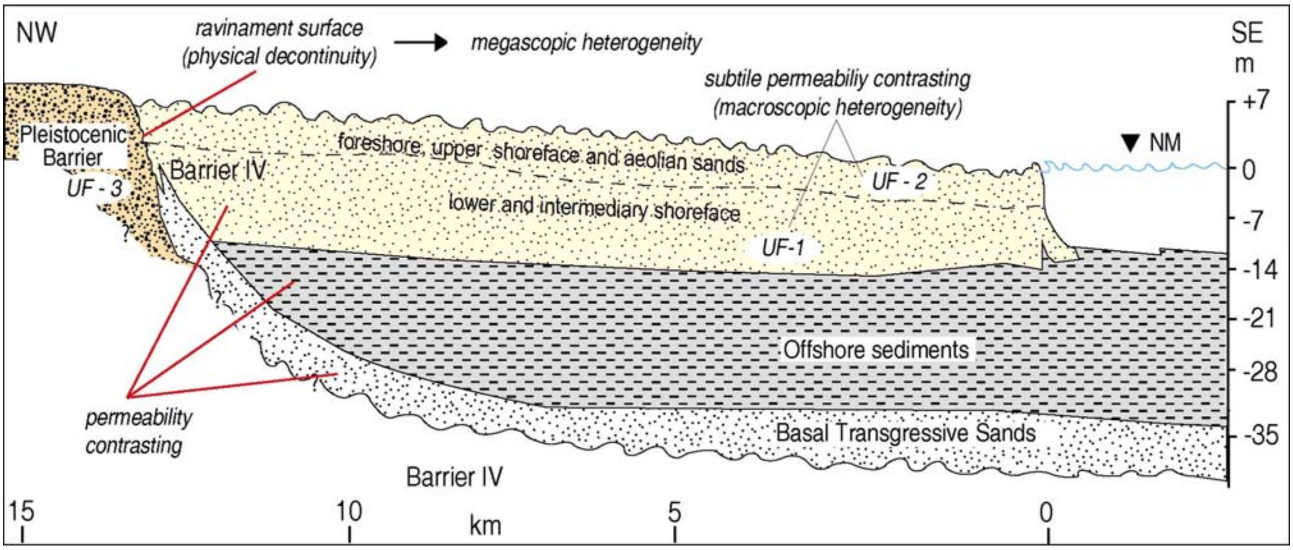

Figure 3 –Geologic profile across the Barrier IV showing the different flow units (UF).

6. Conclusions

For the development of this model is very important to collect more field data and to do other type of investigations, like permeability tests and seismic profiles.

However the interpretation proposed is according with the avaiable data and considers the evolutionary model constructed to the Holocenic Barrier, what is of great importance for this kind of study. The study of analogous reservoir is a good technique to understand the sedimentary patterns and facies distributions thats controls the distribution of permeability and porosity in sand bodies. The detail of the initial characteristics and depositional conditions as to post-depositional modifications superimposed to the potential reservoir is a good way to predict important configurations that must be led in account to the hydro-carbons or water exploration.

7. Acknowledgements

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