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GEOLOGY OF THE COASTAL PROVINCE OF RIO GRANDE DO SUL, SOUTHERN BRAZIL. A SYNTHESIS*

Jorge Alberto Villwock**

ABSTRACT

The Coastal Province of Rio Grande do Sul comprises two large, distinct geological areas, the Basement and the Pelotas Basin.

The first, a platform consisting of Pre-Cambrian basement complexes and Paleozoic to Mesozoic sedimentary and volcanic sequences of Paraná Basin, both submitted to sucessive downwarplings as a result of the tectonics which were characteristic of the South Atlantic opening during the Cretaceous, was the source of the second, an open marginal basin. Since then, the Pelotas Basin started receiving a clastic load resulting from the dissection of adjacent highlands. Sucessive transgressions, which were controlled in the beginning by tectonics and from Tertiary onwards by global sea-level changes, provided an accumulation of a clastic sequence (gravels, sands and mud), more than 5.000 meters thick, in which carbonatic layers are very rare, and there are no evaporitic layers so characteristic of the other basins of the Brazilian continental margin. Geological and geomorphological mapping of the upper part of this sequence which is exposed on the Rio Grande do Sul Coastal Plain, show that it consists of a set of sedimentary facies, discontinuous in space and in time, resulting from the displacement of several sedimentation environments (continental, transitional and marine) over the same region. Besides the sedimentologic characterization of deposits as shallow-marine, beach, eolian, lagoonal, paludal, deltaic, fluvial and alluvial fans, the studies

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showed large accumulations of black sands (titanium and zirconium), sands for building purposes and the glass industry, clays for ceramics, diatomites, shell deposits and large peat deposits. The exploitation of these mineral resources performed within an appropriate program of coastal management, will only be prevented from causing ecological damage if this gigantic and complex, vulnerable coastal system is fully known.

RESUMO

A Província Costeira do Rio Grande do Sul é constituída por dois grandes domínios geológicos distintos, o Embasamento e a Bacia de Pelotas.

O primeiro, uma plataforma composta pelo complexo cristalino pré-cambriano e pelas seqüências sedimentares e vulcânicas, paleozóicas e mesozóicas, da Bacia do Paraná, submetido a sucessivos basculamentos resultantes da tectônica que acompanhou a abertura do Atlântico Sul, durante o Cretáceo deu origem ao segundo, uma bacia marginal aberta. Desde então, a Bacia de Pelotas passou a receber a carga clástica derivada da dissecação das terras altas adjacentes. Sucessivas transgressões, controladas no princípio pela tectônica e a partir do Terciário pela variações globais de nível do mar, proporcionaram a acumulação de uma seqüência clástica (cascalhos, areias e lamas) com mais de 5.000 metros de espessura, onde são muito raras as camadas carbonáticas e estão ausentes as evaporíticas tão características das demais bacias da margem continental brasileira. Mapeamento geológico e geomorfológico da porção superior desta seqüência que se expõe na Planície do Rio Grande do Sul e que configuram a superfície desta região, mostram que ela é constituída por um conjunto de fácies sedimentares, descontínuas no espaço e no tempo resultantes do deslocamento de diversos ambientes de sedimentação (continentais, transicionais e marinhos) por sobre a mesma região. Além da caracterização sedimentológica de depósitos marinhos rasos, praias, eólicos, lagunares, paludais, deltáicos, fluviais e de leques aluviais, os estudos evidenciaram acumulações importantes de areias negras (titânio e zircônio), areias para construção civil e indústria do vidro, argilas para cerâmica, diatomitos, concheiros e grandes turfeiras. A exploração destes recursos minerais, efetuadas dentro de um programa adequado de manejo costeiro, só não ocasionará danos ecológicos se este gigantesco e complexo ecossistema costeiro, vulnerável pela sua própria natureza, for perfeitamente conhecido.

INTRODUCTION

The geological provinces developed along the Atlantic-type or accretion-type continental margins, are sites with large sedimentary accumulations caused by mechanisms which frequently also led to a genesis of a range of mineral concentrations of great economic significance.

Most of the geological processes causing this type of accumulation are still active on the present surface of these provinces which usually consist of a coastal plain and a continental shelf. The boundary between these two is an effemeral coastline, depending on three factors which work separately or together, i.e., the rate of sediment supply, the rate of subsidence and sea level variations.

Thus, it is in these regions that morphological features and sedimentary deposits are found relatively well preserved, having been produced in continental, transitional and marine environments, and it is here that the Uniformitarian doctrine "the present is the key to the past", proposed by James Hutton almost two centuries ago, can be applied. In fact, here it is possible to compare Ancient and Modern, and the Ancient can be studied at different stages of change, so as to establish sedimentation models which are so important for interpreting environments of the past and indispensable in understanding older geological systems.

Since in these systems there are large accumulations of fossil fuels (peat, coal, oil and gas), beach placers (monazite, ilmenite, rutile, zircon, diamond, gold, etc.), large deposits of materials used in the building industry (sands, clays, limestones) it is needless to mention the economic significance of detailed information on the subject.

On the other hand, in these coastal regions which are transicional areas between land, sea and air, the combined action of these stages has a profound influence on the media dynamics, generating an intricate, sensitive ecosystem which is influenced by Man, a transforming agent of the first magnitude. It is in the coastal areas that large urban developments take place, becoming centers of intense economic activity, trade, transportation and communication, activity as a response to the advantageous conditions supplied for the portuary development, continuous use of renewable and non-renewable resources and also, the development of recreation and leisure centers. Almost always, the impact of intense and uncontrolled use of these regions has a direct effect on the ecosystem, often resulting in irreversible damage.

Thus, the full development of these areas requires rational management and administration of resources. Apparently these objectives are contradictory, on the one hand, is the need to preserve the region and/or conserve natural resources, on the other to develop and use its riches.

However it may be, the preparation of a coastal management program, balancing regional conservation and development, requires a multidisciplinary scientific and technological effort. This procedure, which is current practice in

developed countries, as quoted by Lévy (1978), Vallejo (1977) and others, has still not reached the coastal region of Rio Grande do Sul, one of the most complex in Brazil and perhaps one of the most severely menaced ones, from the ecological point of view, in present times. This aspect has been emphasized by Villwock and Martins (1978).

In order to full acquire knowledge of the physical base of this ecosystem and survey the mineral resources which can be used in economic development, the Oceanic and Coastal Geology Center of Studies of the Institute of the Institute of Earth Sciences of the Federal University of Rio Grande do Sul, has been concentrating research efforts along what, Villwock (1972), using the criteria proposed by Murray (1971), called Coastal Province of Rio Grande do Sul, a group of geological elements (tectonic, structural, sedimentary and morphological) characteristic of the Brazilian continental margin between parallels 28°40' and 33°45' latitude S.

Besides showing the present status of geological information on this region, this study proposes a synthesis of all literature available on the subject, to facilitate the execution of new research projects related to the Coastal Province of Rio Grande do Sul.

STRUCTURE

The Coastal Province of Rio Grande do Sul consists of two large geological elements: the Basement and the Pelotas Basin which settled over it. See Fig. 1.

To fully understand the geological evolution of this area it is necessary to analyze its main structural aspects, as follows.

THE BASEMENT

The sedimentary sequence accumulated in the Pelotas Basin is settled on older rocks which make up the Uruguayan Shield, which is a component of the South American Platform. North of the parallel which passes through the city of Porto Alegre it lies on the sedimentary and volcanic, Paleozoic and Mesozoic sequences which are part of the Paraná Basin.

Recent studies by Fragoso Cesar et alii (1982 a, b), have attempted to summarize existing geological information about the Shield, and try to interpret its evolution by applying the plate tectonics model. According to their proposals, a geotectonic unit is observed there, which was generated during the Brasiliano cycle (late Proterozoic, Early Paleozoic). The Dom Feliciano Belt, a NE-SW mobile belt, developed on the eastern border of the La Plata River Craton (Archean – Lower Proterozoic), configuring a collision zone for two continental masses. The La Plata River Craton is composed of an ancient Plutonic Volcanic, and sedimentary sequences, which were polydeformed and polymetamorphized under conditions of amphibolite and granulite facies, generating various granitoids, ortho and

paragneisses which are partially plurimagmatic, associated to metasedimentary remnants (amphibolites, pyroxenites, gabbros, anorthosites), all of them constituting high grade old gneissic nuclei, which are also joined by greenstone belts, metavolcanics composed by ultramafics, mafics and felsics, with interbedded metasediments.

The Dom Feliciano Belt consist of various petrotectonic associations, as follows in brief:

a — Association of passive continental margin — Quartzites, meta-arkoses, phyllites, schists, marbles, and meta-marls, resulting from low to medium-grade metamorphic evolution of a pre-orogenic detrital-chemical sequence which has accumulated on a passive, Atlantic-type, continental margin.

b — Marginal basin association — A complex sequence composed of meta-andesites and meta-dacites, with pillow lava structures, interfingering by meta-tuffs, aluminous schists, graphite schists and very few quartzites and marbles which have evolved from a volcanic-sedimentary sequence which has accumulated in a marginal basin adjacent to the magmatic arch generated during the orogenic phase of the Brasiliano cycle. During continental collision this sequence was upthrust towards NW over the Passive Continental Margin Association.

c — Magmatic Arc Association — The central part of Dom Feliciano Belt, is made up by large polyphasic granitoid complexes represented by broad anatexitic and migmatitic areas, with which numerous multi-polyhaedric, polydiapiric complexes are associated, with sin —, tardi — and post-tectonic phases, in which more recent intrusions cut into or surround older ones. In the migmatitic areas there are occurrences of irregular spots, remnants of gneisses, amphibolites, schists, quartzites and marbles, with which granitoids have gradational intrusive and tectonic contacts. The granitoids are calc-alkalic to sub-alkaline, rarely alkaline, varying in composition from quartz-diorite to granite. Dikes and apophysis of porphyrous granites, aplites, rhyolites, and granophyres create the outline of the group described above.

d — Frontal Basin Association — Phyllites, chlorite schists and quartzites, results of epimetamorphic evolution of anaccumulated volcanic-sedimentary sequence, probably in a basin which lies in front of the magmatic arc. It occurs at the far southeast of the Shield.

e — Molasse Sedimentary Association — Consists of thick detritic marine accumulations at the base and continental red layers at the top, which fill the pre-trench of the Southeast, a molasse trench which appeared between the Dom Feliciano Belt and the La Plata River Craton, at the end of the Brasiliano Cycle.

f — Plutonic — Volcanic Sedimentary Molasse Association — Accumulated on the unstabilized cratonic margin and consisting of andesitic volcanic cycles at the base and rhyolitic cycles at the top, interbedded with volcanoclastic and pyroclastic matter. Associated occurrences of cogenetic granitic bodies.

With this composition the La Plata River Craton and Dom Feliciano Belt make up the Pre-Devonian Basement of the South American Platform. The geotectonic evolution of this region is handled similarly by Issler (1982). The large fold and faults structures there, occur predominantly in NW-SE directions, as had already been shown by Picada (1971). The Paraná Basin settled on this Basement from the Devonian onwards.

Almeida (1961) considers this a large geotectonic unit which overlay the South American Platform right after the stabilization following the Brasiliano Cycle. It is a basin with a stable, remote, interior, according to the classification by Weeks, (1952) or a simple interior, Type — I cratonic basin, according to Klemme (1971).

The configuration and tectonic behaviour of the Paraná Basin were greatly influenced by structural features of the crystalline basement, such as warping, flexures, lineaments and areas with more subsidence.

From the Devonian to the Upper Jurassic, evolution took place as a synclisis, where tectonic stability increased as shown by sea transgressions which were soon transformed into more confined epicontinental seas, culminating in the predominance of transitional and continental environments.

From the Upper Jurassic onwards the Vealdenian Reactivation processes related to the beginning of the opening of the Atlantic Ocean, profoundly modified basin characteristics, transforming it into an amphyclisis where magmatic and tectonic processes amply overcame sedimentary ones.

In Sanford & Lange (1960) and Schneider et alii (1974) full descriptions of the main stratigraphic units which were heaped up in this approximately 1.750.000 km² — sized basin can be found. On the other hand, in Tommasi (1973), there is a review of the southeast basin flank, which is supported on the Sulriograndese and Uruguayan Shield, forming a set which, already during the Cretaceous became a basement for the Pelotas Basin and since then has acted as source for terrigenous clastic sedimentation which accumulated there until the Holocene.

In Rio Grande do Sul, the Paraná Basin sedimentation begins during the Middle Permian, with periglacial deposits (diamictites, rhythmities, shales) of the Rio do Sul Formation, Itararé Group. Next there is Guatá Group, Rio Bonito, and Palermo Formation, in which siltites, sandstones, conglomerates, carbonaceous shales and coal layers accumulated in a fluvial deltaic and shallow marine environments. In the Upper Permian the great transgressive-regressive cycle which began with the Palermo Formation caused the accumulation of the Passa Dois Group, consisting of the Irati, Serra Alta, Teresina and Rio do Rasto Formations, a sequence of shales and marine limestones which are sometimes pyrobituminous, argillites, shales and shallow marine siltites; siltites and fine sandstones from deep marine to shallow marine and transitional, culminating in argillites, siltites and river continental environment sandstones.

The continental phase which extends into the Mesozoic provides the accumulation of Rosário do Sul Formation sandstones which were deposited in a fluvial and associated lake environments. Then follows São Bento Group, consisting of Botucatu Formation sandstone, accumulated in a desert environment over which the basic and acid lavas of Serra Geral Formation flowed (Upper Jurassic-Lower Cretaceous).

In the northern part of the Rio Grande do Sul Coastal Province, where the Pelotas Basin basement consists of the Permo-triassic sequences of the Paraná Basin, intensive geological work is underway to explore and exploit the coal deposits included in the Rio Bonito Formation. The coal which outcrops near the town of Gravataí, occurs to a depth of 800 meters at the Santa Terezinha beach resort, along the present coastline. Further details can be found in Bortoluzzi et alii (1980) and in Camozatto et alii (1982).

THE PELOTAS BASIN

Although the name Pelotas Basin had been in use since the 1950's, in oil prospection work carried out by PETROBRÁS (Clemins, 1957), Ghignone (1960) was the first author to use this name officially to define a broad Tertiary and Quaternary sediment-filled basin, with a surface occupied by Patos and Mirim Lagoons, besides others on the Rio Grande do Sul Coast.

Since then, many papers have been written on the structure and tectonic development of this region, almost all of them directly or indirectly related to oil prospection. Only the most significant will be presented, and in them the reader will find complementary references.

Medeiros (1966), Meister (1969), Miranda (1970), Butler (1970), Urien & Zambrano (1970), Leyden et alii (1971), Asmus & Porto (1972), Meister (1973), Ojeda and Cesero (1973), Kowsmann et alii (1974), Ojeda and Silva (1975), Urien et alii (1976), among others, present data and discussions, collected and reevaluated by Gonçalves et alii (1979).

More recently, new information was added by Asmus (1981), Asmus and Guazelli (1981) and Ojeda (1982).

The Pelotas Basin is an open marginal basin of the stable coastal type (Weeks, 1951), or V-type, intermediate, stable or broken coasts of Klemmes's classification (1971). It comprises the meridional segment of the Brazilian continental margin, south of the Florianópolis Platform, and covers an area of approximately 70.000 km², with its external limits chosen at the 200-meter isobath.

Its origin is definitely related to the geotectonic events leading to the opening of the South Atlantic Ocean from the Jurassic Period onwards, which resulted in the rupture of the Gondwana continental block and later separation of the African and South American continents.

According to Asmus (1981) and Asmus and Guazelli (1981), the tectonic-sedimentary and tectonic-magmatic processes which caused the formation of the Brazilian marginal basins began with the Wealdenian Reactivation of the Brazilian Platform (Almeida, 1967) and developed in four main stages: pre-rift, rift-valley, protooceanic and oceanic, leading to the respective deposition of the sedimentary sequences of the Continent, the Gulf, the Lakes and The Sea.

In the Pelotas Basin, as far as is known, to the contrary of most of the other basin of the Brazilian continental margin, where there is evidence of all the above mentioned stages, sediments started to accumulate during the oceanic stage with the deposition of the Sea Sequence during the Aptian, by progressive separation of the South American and African continental masses, and the formation of an ocean floor from the Middle Atlantic Ridge. According to Gonçalves et alii (1979) also there is no visible record of tectonic episodes of the first evolutionary stages of the continental margin. The most obvious signs of tectonic activity are faults in the basement, sub-parallel to the coast, creating large asymmetric, echelonated grabens, systematically deeper eastwards. They are the result of the successive downwarps of the continental margin, which would break when going along with the subsidence of the adjacent oceanic crust being submitted to cooling.

Asmus & Guazelli (1981) called these features hinge lines or flexures. They are essentially parallel to the structural direction of the basement, and were formed in the Albo-Aptian which was deepest and furthest away from the coast and during the Paleocene nearest to the coast and shallowest. In the Pelotas Basin, the Albo-Aptian hinge line is most prominent, and separates a zone where the top of the basement is relatively shallow and dips gently, from another where the basement deepens rapidly with a pronounced dip, dividing it longitudinally into a Shallow Basin in the west, where there is recent sedimentary action, and a Deep Basin in the East, where there are more ancient sediments.

The Paleocene hinge line occurs further west and is less noticeable since it was attenuated by later erosive processes.

Miranda (1970) had called the Albo-Aptian hinge line the Rio Grande Fault, the Shallow Basin, the Patos Lagoon Platform and the Deep Basin, the Pre-Tertiary Basin. In the places where post-downwarping erosive processes were not intense, compensation grabens, as they were called by Ojeda (1982) were preserved, filled by more ancient sediments, dipping seawards. The Albo-Aptian compensation graben is best developed in the Pelotas Basin and is up to 20 km wide.

The Mostardas Trough mentioned by Gonçalves et alii (1979) is the result of a marked Westward inflexion of all components of the Albo-Aptian rupture zone, which are almost as high as the present coastline. An identical displacement is seen in the Paleocene rupture zone.

Other faults observed in the Pelotas Basin sedimentary sequence are adiasporphic. They are growth faults with small slips which affect the Tertiary, particularly near the Mostardas Trough.

The most prominent transversal structure, as indicated by Asmus and Guazelli (1981) are the Florianópolis, Porto Alegre and Chuí Lineaments. The Florianópolis Lineament is marked by a submarine volcanic line which, together with the Walvis Range was responsible for the meridional restriction of the Aptian evaporitic basin. It represents the septentrional boundary of the Pelotas Basin and the Rio Grande Rise. The Porto Alegre Lineament establishes the southern boundary of the Rio Grande Elevation, and that of the Chuí, the meridional boundary of the Pelotas Basin. The authors also attempt to correlate these structures to some features of the adjacent continental area.

There is also no evidence of modern tectonic activity in the emerged part of Pelotas Basin. The Coxilha das Lombas Fault system characterized by Delaney (1965) and described by Picada (1970) was contradicted by Jost (1971). Villwock (1972) showed that the linear nature of that feature is related to an ancient line of sea cliffs controlled by a fault line developed along Pre-Cambrian fractures, which has been partly buried by aeolian deposits. Recent papers by Camozatto et alii (1982) confirmed these observations, since the coal layers drilled on either side of the supposed tectonic alignment presented similar heights and the same regional dip.

Obeying the structural control which has just been describe, sediments accumulated in the Pelotas Basin to a thickness of about 8.000 m. In the shallow part, thicknesses do not exceed 3.000 m, but in the deepest part, Carvalho & Francisoni (1981) established three semi-isolated compartments. The North depocenter in front of Cape Santa Marta, has 6.000 m of sediment; the Central depocenter at the latitude of Porto Alegre, has slightly over 7.000 m, while the third depocenter, in the southern part of the basin facing the city of Rio Grande, shows aproximately 8.000 m of sediments.

THE STRATIGRAPHY OF THE PELOTAS BASIN

SUB-SURFACE

The first geological investigations performed in the sub-surface in the emerged portion of Pelotas Basin, were reported by White (1908) who describes samples from drillings performed in Pelotas, between 1856 and 1862. The presence of greenish sands and ill-preserved fossils lead the author to assume that they were Cretaceous in age.

Carvalho (1932) and Martins (1952) refer to the same drillings, and restudying the fauna of Mollusk and Brachiopoda found there, consider them as belonging to the Tertiary.

Oil prospection began in 1939, and Targa (1943) reports the first drillings in Ponta Alegre, County of Arroio Grande, a concession belonging to C.G. Rheingantz. That author admits to the existence of Cretaceous/Tertiary marine

sediments in the Atlantic littoral strip of Rio Grande do Sul. Rheingantz (1955) presents a report on activities in this concession.

Additional information on the sub-surface stratigraphy of the basin were obtained when oil prospection by PETROBRÁS began, in the second half of the fifties. Basic literature on the subject is the same as for the previous chapter. Besides the data generated by measuring gravimetry, magnetometry and seismics, analysis of data from drillings in the emerged portion of the basin (Table nº 1) was a definite milestone in establishing local stratigraphy.

Besides the PETROBRÁS internal reports, many papers have been published with data from samples taken in these stratigraphic wells:

Closs (1966, 1967, and 1970) studied the Foraminifera and correlates the several wells. Of these, 2-MO-1-RS shows the most complete sedimentary sequence and is the type-section for the shallow part of Pelotas Basin.

There, according to the author, the basement is covered by a basal, afossiliferous, continental conglomerate, considered as Pre-Miocenic. A sequence of marine clastics of the Early Miocene transgresses on the conglomerate and is in its turn covered by shales from the Late Miocene. These graded to predominantly gross Plio-Pleistocene clastics, which are covered by Holocene sands with variable amounts of silt and clay.

Forti (1969) studied the mollusks found in wells 2-PS-1-RS and 2-CI-1-RS and considered them Holocene as opposed to previous ideas considering them Pleistocene.

Later an Forti-Esteves (1974), ended the study by comparing mollusks from outcrops in the county of Santa Vitória do Palmar to those in wells 2-CI-1-RS (9-36 m and 87-213 m), and 2-PS-1-RS (24-25 m), this confirming their Holocene age.

Daemon (1969) studies the palynoporphs in the Mostardas, Cassino and Palmares do sul wells, establishing a preliminary biostratigraphic column.

Fernandes (1975) and Thiesen (1977) studied those from 2-CI-1-RS and 2-MO-1-RS, both establishing informal biostratigraphic zones and commenting on the paleoecology of the sediments from the Pliocene to the Recent age.

Sanguinetti (1970, 1980) makes a taxonomic study of the Miocene Ostracoda and Ornellas (1981) of the Post-Miocene Ostracoda contained in the samples from the same wells. Both establish biostratigraphic zoning and comment on the paleoecology of the faunistic associations described.

The chronostratigraphic results of all these papers do not agree on many points. A discussion on the subject is presented by Ornellas (1981).

More recently Madeira-Falcetta et alii (1980) studied sediments and microfauna of two groundwater wells, PDS-3 (Palmares do Sul) and ALB (Albatroz swimming resort), drilled by the Rio Grande do Sul Company of Sanitary Engineering (CORSAN) and there defined lagoon and marine sequences alternating between the Pleistocene and the Recent age.

Boltowskoy et alii (1983) described Foraminifera from four wells drilled for coal prospection, in the Northeast region of the shallow part of Pelotas Basin, by the Company for Research of Mineral Resources (CPRM). The sections drilled are from the Miocene to the Recent, and accumulated in a marine and transitional environment.

In spite of all this data, the best overall view of the stratigraphy of sediments accumulated in the Pelotas Basin was obtained in studies by PETROBRÁS, especially those published during the Seventies, when the submerged part on the continental margin was explored. This information was increased manifold by using reflection and seismic refraction techniques as well as two submarine wells drilled there, 2-RSS-1 and 1-RSS-2.

In the same way, the detailed study of the other marginal basins on the Brazilian coast, for the purpose of exploring and exploiting the oil-producing potential, supplied new data and ideas on stratigraphy. The most useful tool has been seismostratigraphy.

As has already been mentioned in the previous chapter, of the large depositional sequences identified in those marginal basins by Asmus (1981) only the Sea Sequence which accumulated since the Aptian, has been found up to now in the Pelotas Basin.

Gonçalves et alii (1979) after commenting on the impossibility of a formal lithostratigraphy due to scarcity of information, present informal chronostratigraphic units obtained with seismostratigraphic analyses using well data as reference points. The limits of these units coincide with the more evident transgression episodes which, according to Estrella Braga & Della Favera (1978), quoted in Asmus & Guazelli (1981) are practically the same limits as those of the main cycles of overall variation in sea level, established by Vail et alii (1977).

The units mentioned are the following, according to the descriptions by Gonçalves et alii (1979):

UNIT I — is represented by sediments deposited up to the downwarping and Albo-Aptian rupture episode. It fills the compensation graben, and is the oldest deposits on the east of the hinge line of the same age. There are marked dips and, although the sequence has not been perforated and has been eroded in the proximal portions, it is estimated that it is composed of marine sediments synchronous with the evaporites occurring in the basins north of the Florianópolis Platform.

UNIT II — includes Cretaceous sediments after the Albo-Aptian downwarping episode and its deposition is partly related to the resulting erosive processes. It covers UNIT I in angular discordance and is directly supported on the basement, west of the hinge line and associated grabens.

Its sedimentation resulted in a constructional platform in which, from West to East are seen a narrow strip of slope and a deep water region, where well 2-RSS-1 traversed deep water shales with interbedded calcilutite and calciferous shales. Well 1-RSS-2 on the shelf border traversed a series of interbeddings of sandstone

shale, calcarenite and calcilutite. Well 2-MO-1-RS traversed conglomerates of clayey matter which Ojeda & Silva (1975) consider part of this unit.

UNIT III — begins with a transgression and the point of passage from the Cretaceous to the Tertiary which projected the constitutional slope westwards. Prograding sedimentation culminated in forming a broad constructional shelf.

In 1-RSS-2, the upper part of the unit was removed by erosion and what remains is a sequence of 300 m, comprising essentially shales, with interbedded turbidites in the upper part. In 2-RSS-2, there are already 1,200 meters of this UNIT III composed of shales at the base, shales and sands in the middle upper part and calcilutites at the top. Their presence in 2-MO-1-RS is marked, according to Ojeda & Silva, (1975), by conglomeratic clayey sands.

UNIT IV — is related to the downwarping episode which occurred approximately at the time of passing from the Paleocene to the Eocene, and is made up of a sedimentary wedge deposited in onlap over the submerged part of the downwarped block, submitted to intense erosion.

It occurs away from the littoral area and was only identified in the longer seismic lines facing the Mostardas Trough.

UNIT V — begins with a transgression which occurred around the Middle Eocene and can be very thick. In 1-RSS-2 throughout the 1,100 m drilled, smaller transgressions and regressions are observed, causing advances and recessions of the constitutional slope, giving rise to vertical successions of sediments of different paleoenvironmental character.

In 2-MO-1-RS, the sequence proved predominantly sandy with interbedded marine clays, whereas in 1-RSS-2, UNIT V begins with 200 m of deep water shales, followed by interbedded shelf and slope shales, respectively sandy and clayey, the sand increasing toward the top. At 2-RSS-1, further distally, there are essentially deep water shales, with sandstone only in the upper part.

The sandstones vary from fine to coarse and represent both shelf deposits and turbidites, depending on their position. In the seismic section planar reflector, with excellent contrast, small-sized progradations and local evidence of cut and fill of canyons can be observed.

UNIT VI — begins with a transgression which occurred approximately at the limit between the Eocene and the Oligocene, UNIT VI is not very thick and comprises Oligocenic sediments consisting of deep water shales, with sandy interbedding in the more proximal portions. It was identified in wells 2-MO-1-RS, 2-RSS-1 and 1-RSS-2.

UNIT VII — during Early Miocene, a large transgression started the sedimentation of this UNIT causing the deposition of marine shales up to beyond 2-MO-1-RS, where there is now continent.

From this episode on, a proximal depositional system was developed, forming barriers and lagoon with deltas fixing the coarse terrigenous material transported by the drainage system, as is now observed in the coastal region of Rio Grande do Sul.

After this, the sedimentary contribution to the marine portion of the Pelotas Basin was practically reduced to the deposition of pelites.

Thus, this UNIT is essentially composed of marine shales which were drilled in the three above-mentioned wells. With discontinuous seismic reflectors it is recognized throughout the whole basin.

UNIT VIII — during Middle Eocene, a transgression pushed the transgressional slope westward, beginning a new sedimentation cycle which extends, with small fluctuations, until the Holocene.

2-MO-1-RS traversed a sequence of fine sands and clays which are a proximal expression of UNIT VIII. 1-RSS-2 drilled through shales and shelf argillites and 2-RSS-1, although drilling a cross section essentially made up of pelites, reflects several environments: deep-sea basin shales at the base, slope shales on the middle upper part, covered by an approximately 500 — meter set of shelf shale and argillite layers.

From what has been described in the sedimentary sequence accumulated in Pelotas Basin there are no carbonatic platforms and huge evaporitic deposits which are characteristic of the other basins of the Brazilian continental margin.

Gathering data presented by Ojeda & Cesaro (1973), Ojeda & Silva (1975), Gonçalves et alii (1979), Sanguinetti (1980 and 1981), Ornellas (1981), Asmus & Guazelli (1981) and Ojeda (1982), a schematic geological cross-section was prepared, transversal to the basin, passing through wells 2-GA-1-RS, 2-MO-1-RS, and 2-RSS-1, seen in Fig. 2.

Since its formation, the Pelotas Basin accumulated terrigenous clastics which were mobilized in continental, transitional and marine depositional environments, displaced in space and time at the whim of variations in the erosion base level, initially related to tectonic processes and later to eustatic fluctuations which occurred markedly during later geological times.

Consequently a predominance of coarse facies is noted (conglomeratic and sandy-conglomeratic-clayey) accumulated in a system of deltaic fans, in the shallow part of the basin, being replaced by finer facies (sandy, sandy-clayey and clastic carbonatic), which accumulated in shelf systems and, in the deeper part of the basin, a predominance of very fine facies which accumulated in slope systems.

The more modern part of the sedimentary sequence which is part of the deltaic fan system is exposed in the Coastal Plain of Rio Grande do Sul, and will be described next.

SURFACE

Due to the specific characteristics of a broad lowlands region, bordered by a wave-beaten, wind-swept sandy coast over 640 km long, the Coastal Plain of Rio Grande do Sul has, for a long time, called the attention of visiting experts.

The first papers published are from the second half of the last century up to 1962, and a complete list is presented by Delaney (1965). Usually these studies involve aspects concerning Anthropology, Geography, Zoology, Botany, Paleontology, Geology and Coastal Engineering related to the area. The main data were added to those obtained by the above-mentioned author in his "Physiography and Surface Geology of the Coastal Plain of Rio Grande do Sul", the first overview published about the region, and the point of departure for all research which followed.

Using geomorphological and sedimentologic criteria, Delaney (1965) established a series of stratigraphic units whose definitions were later modified or complemented by various authors, amongst whom Morris (1963), Bigarella and Andrade (1965), Jost (1971 a and b), Jost, Pinto and Loss (1971), Villwock (1972), Soliani (1973), Soliani & Jost (1975), Godolphim (1976), Jost & Soliani (1976), Zeltzer (1976), Ayala (1980) and Loss et alii (1982).

The stratigraphy of the Coastal Plain overlying the Pelotas Basin is schematically presented in Fig. 3.

Some of the various units which have now been described are lithostratigraphic (GRAXAIM, CHUI, ITAPOÃ) whereas others are chronostratigraphic (QUINTA, PATOS). They are mostly either informal names which were not given according to the Code of Stratigraphic Nomenclature or else they require redefinition.

The successive proposed modifications, as the results of geological mapping came out, deformed the original descriptions of the units and changed the spatial-temporal position to such an extent, that it is very difficult to understand them properly at first sight.

The low fossiliferous content and/or difficulty in preserving it, plus the great range of lithological diversity, rendered extremely difficult to adopt a criterion allowing the establishment of lithostratigraphic units which can be used throughout the area. Usually it is possible to establish lithostratigraphic units with ages varying from one site to another, since the deposit resulted from a real continuous, cyclic ballet of several specific sediment environments over a same region.

Even so, the lithostratigraphic division, based on a careful sedimentologic study, has proved insufficient to define the general succession of more recent geological events in the region. It was necessary to complement the existing information with data from a detailed geomorphological analysis of features imprinted at the surface. Once the large traits of the regional evolutionary process are established, it becomes easy to interpret certain types of deposits and understand the role they play in the geological landscape of the Coastal Province. The whole region is being studied from this point of view, and experience has shown that, as information on the surface deposits increases, it becomes easier to understand the older sub-surface sequences and the successive events which lead to their accumulation.

For an idea of the main units recognized at the surface of the Coastal Plain, they will be described briefly, below.

GRAVATAÍ – SERRA DE TAPES FORMATION

The Gravataí Formation was defined by Morris (1963) near the town of the same name. Fensterseifer (1979) described three sedimentary facies which can occur singly, interfingered or superimposed. They are mass slide deposits, formed by fragments surrounded by a clayey and clayey-silty matrix. Possibly conglomeratic bodies with sandy matrices form small river channels. The fragments come from neighboring, predominantly sedimentary (Rosário do Sul and Botucatu Formations) and volcanic (Serra Geral Formation) geological units.

The Gravataí formation occurs over the terrains of the Paraná Basin, along the Peripheral Depression and at the boundary of the Coastal Plain, at the base of the scarp which separates them from the Sulriograndense Plateau.

The Serra de Tapes Laterite was described by Delaney (1965) as an edaphostratigraphic unit, exposed along a boundary fringe between the terrain of the Sulriograndense Shield and the Coastal Plain. Later on it was called Serra de Tapes Alterite, by Loss et alii (1974), who characterized it as a group of elluviums, colluviums, alluviums and ferralithized paleosoils. They are sandy-siltic-clayey deposits in ocre and red colors and limonitic concretions and hard-pan. Loss et alii (1982), when studying the geology of the Gravataí River hidrographic basin, found that these two formations are synchoronous and genetically similar. The differences among them are related to the various source areas and to the relief energy, involved in the formation. Both consist of groups of alluvial fans which developed at the inner limit of the Coastal Plain, coming from the bordering highlands.

The thickness is variable and it is likely that the deposition which begun in the Miocene occurred until the Pleistocene-Holocene, under conditions determined by alternative humid and arid climates accompanying the glacial cycles of the northern hemisphere.

GRAXAIM FORMATION

The Graxaim Formation was described and defined by Delaney (1965) and the type-section is PETROBRÁS well 2-GA-1-RS, drilled in Graxaim, Camaquã County.

It occurs along the whole western border, of the Coastal Plain from Porto Alegre to south of Jaguarão, and is constituted by a group of texturally and mineralogically immature, unconsolidated yellow to red sediments, which Jost (1971) grouped in two facies, one conglomeratic and the other sandy-silty. Ayala (1980) described the whole outcrop strip.

Its depositional environment consisted of large alluvial fans built by braided channels and sub-aerial deltas where Closs (1970) identified transgressive interbedded marine levels.

The 270-meter thickness (2-MO-1-RS) decreases westwards where, in many places, an interfingering is observed, with the deposits of the Gravataí-Serra de Tapes Formation. Since it covers the marine sediments of the great Miocene transgression, and is covered by the Chuí Formation deposits, which are Pleistocene, the age of the Graxaim Formation should be Plio-Pleistocene.

CHUI´ FORMATION

Delaney (1965) used this name for quartz, sand sequence with little silt and clay, which accumulated as beach and shallow marine environments. The type-section is located near Arroio Chuí at the Brazilian-Uruguay border.

This formation occurs on the west bank of Patos and Mirim Lagoons, but its most significant surface is acquired in the sand barrier framework separating these lagoons from the Atlantic Ocean.

Jost (1971),Soliani (1973), Jost & Soliani (1976), restudied the Chuí Formation outcrop area and, finding a lateral synchoronous faciological variation, subdivided in into two units: a shallow marine unit, (Taim Member) and a lagoonal facies called Santa Vitória Member.

The Taim Member consists of, yellow, brownish yellow to brown, low silt and clay, sometimes ferruginous quartz sands. Plane parallel lamination and cross-bedding are the main primary structures. The shallow beach marine environment established by Jost & Soliani was confirmed by Tomazelli et alii (1982), who described tubes of *Calianassa major* in outcrops of this unit.

The Santa Vitória Member is composed of fine to medium, light green or greenish yellow, sometimes brownish, quartz sands with parallel lamination, deposited in a lagoonal environment. This unit, originally described by Soliani (1973), contains a fauna of fossil mammals which has been studied by Paula Couto (1953), Cunha (1959), Paula Couto (1969), Paula Couto and Cunha (1965),Soliani & Jost (1980). Other vertebrates have been described b y Cunha and Nunan (1980).

The presence of fossils from this same fauna, in surface sediments covering the present continental platform, such as some pieces of *Megatheriidae*, *Mylodontidae* and *Toxodontidae* which were recently collected at a 46-meter depth between Chuí and Albardão Lighthouse, shows that the site of occurrence of these Pleistocene deposits extends into the sea, quite distant from the present coastline.

GUAÍBA FORMATION

The Guaíba Formation described and proposed by Jost (1979) has its type-section in Guaiba County. It consists of sediments which have accumulated

along submerged river valleys during periods of marine transgression, suggesting a ria coast in the area which is now the western bank of the Patos-Mirim Lagoon system.

Two main facies, a conglomerate one and a sandy one, both markedly mature from the point of view of texture and mineralogy, are the result of river detrital masses, interbedded with fine sediment sequences.

According to Jost (1971), the Guaíba Formation overlies the Graxaim Formation and may be synchronous with the Chuí Formation.

Now, there is a tendency to include in the Guaíba Formation all Pleistocene river deposits occurring in the Coastal Plain. Thick conglomerates described by Leinz (1948), along the Camaquã River valley, which were originally interpreted as being of tectonic origin, seem to be included here.

The deposits in which Bianchi (1969) described fossil oysters banks in the towns of Pedro Osório and Pelotas, must also be considered. The author considers them Pleistocene age and from an estuarine environment, and calls and calls the group of quartz-feldspar sands with conglomerate and clayey interbedding, there described, the Piratini Facies, a sub-unit of Graxaim Formation.

Their Upper Pleistocene age (29.405 B.C.), according to Forti-Esteves (1974), prevents considering them as a much older Graxaim Formation Facies. It is likely that the Piratini estuarine facies deposits are lateral variations either of the Guaíba Formation or of the Santa Vitória Member of Chuí Formation, which are all synchronous.

ITAPOÃ FORMATION

Itapoã Formation was described and defined by Delaney (1965) and is located typically on Itapoã Peninsula, in Porto Alegre County. The formation was redefined by Jost (1971) and by Jost et alii (1971) and includes medium to fine quartz sands, well selected, with up to 15% silt-clayey. The cement is ferruginous. Colors vary in tones of yellow-brown, ocre and red.

Although the primary structures had almost always been destroyed by post-depositional processes, in many places large plain cross-bedding are preserved, such as described by Martins et alii (1980), near Torres.

The Itapoã Formation deposits, according to Jost (1971), constitute a succession of elongated fields of regressive dunes, of the Pleistocene age, and are synchronous with the Chuí Formation. Both constitute the greater part of the terrains which make up the barrier separating the Atlantic Ocean from the Patos-Mirim lagoon system.

QUINTA FORMATION

Quinta Formation includes all modern and some slightly older deposits, which Delaney (1965) included in the Recent of the Coastal Plain, and which

extend from the East scarp of Chuí Formation up to the Atlantic coastline and also along the entire plain.

Villwock (1972) showed that during Holocene, environmental conditions of alluvial, river, lagoon, paludal, aeolian and marine sedimentation are acting on the coastal region in intimate association. This renders a stratigraphic ordering of deposits which accumulated in the region during this time, very difficult.

It has been found that the processes which originated the deposits of the Serra de Tapes, Guaíba, Chuí and Itapoã Pleistocene formations are still active. As an example, the continental shelf and beach deposits which accumulated in the upper part which has already emerged, are equivalent to those of the Chuí Formation, whereas the extensive long dune fields extending along the present coastline, inland, correspond to those of the Itapoã Formation. Since the moving sedimentary material originates mainly from reworking older deposits, as far as lithological and environmental characteristics are concerned there are no marked differences between Pleistocene and Holocene accumulations.

Nevertheless, Godolphim (1976) gives the generic name of Quinta Formation, to a group of beach, marine, lagoonal and aeolian deposits which outcrop in the littoral strip and accumulated after the major Holocene transgression.

GEOMORPHOLOGY AND SEDIMENTATION

The various studies attempting to describe the large geomorphological domains of Rio Grande do Sul, amongst which Leinz (1945), Nogueira (1948), Monteiro (1968), Thofehrn (1969), Ab' Saber (1970), and Carraro et alii (1974), should be emphasized, there is a clear presence of four physiographic compartments, as a result of morphoclimatic processes acting on areas with a different geological composition: the Plateau, the Sulriograndense Shield, the Peripheral Depression and the Coastal Plain.

The Plateau is made up of a surface with a slight westward dip, where altitudes vary from 1000 meters in the Northeastern region to 200 meters in the Western part of the state, modelled on volcanic sequences of Serra Geral Formation.

The Sulriograndense Shield is a wavy surface, with altitudes varying between 600 and 200 meters. It is developed at the expenses of igneous and metamorphic sequences of the Dom Feliciano Belt and the La Plata River Craton, and its sedimentary and volcanic Eopaleozoic cover.

The Peripheral Depression is a broad peneplain installed in the middle region of the state, between the Plateau and the Sulriograndense Shield. Altitudes are below 200 meters, and the surface is made up of large river plains installed over sedimentary formations on the southern border of the Paraná Basin.

The Coastal Plain is a broad area low land with less than 200 meters altitude, Cenozoic unit outcrops, described in the previous paragraphs.

Thus it is easy to understand that both the Plateau and the Shield are highlands which have since a long time been source areas for the sediments which accumulated in the lowlands of the Peripheral Depression and especially the Coastal Plain.

Besides the elluviums, colluviums and alluvial fans now seen of the slopes on the Plateau and the shield, the sedimentary materials produced by the dissection of these highlands travel through the river systems, building up alluvial plains and, upon arriving in the large lagoon system dominating the Coastal Plain, they build up deltas which imprison most of the coarse clastics. In the lagoon system, the wave and current action generated by local winds builds beaches and redistributes the fine clastics which end up in the sea through the action of the few interconnecting channels.

Separating the lagoon systems from the ocean there is a broad sandy barrier sculpted by lagoon, river, aeolian and marine processes which accompanied the eustatic oscillations of the Cenozoic Era.

The Coastal Plain of Rio Grande do Sul is, thus, an excellent natural laboratory to study and understand the depositional environments of terrigenous clastics, as intended by Hayes and Kana (1976). This is impossible without a solid geomorphological analysis of the deposits which accumulate there, which had already been recommended by Potter (1957).

Thus, next, the main geomorphological and sedimentologic aspects of the Coastal Plain will be analysed for gathering data to establish the paleographic disposal of the depositional systems which built it.

Many papers have dealt with the geomorphology of this region. Some even perform paleographic reconstruction. They will be mentioned in the text.

Despite the pioneer observations made by Smith (1901) Backheuser (1918), Lamego (1940), Sena Sobrinho (1950), it was Delaney (1961-1965) who provided the first overall view of Coastal Plain geomorphology in several publications.

New data were added by Jost (1971), Villwock (1972), Soliani (1973), Zeltzer (1976), Godolphim (1976) Jost & Soliani (1976), Gomes (1976), changing the physiographic picture presented by Delaney.

Adding this information to what has been obtained during the systematic mapping of the coastal region and its integration with sedimentologic data available, allows the characterization of depositional systems installed in the area during later geological times.

The morphological compartments of the Rio Grande do Sul Coastal Plain are resumed in fig. 4 and are follows.

INNER ALLUVIAL PLAIN

It comprises the lowlands between the Sulriograndense Shield and the large lagoons of the Patos-Mirim System. It extends from Porto Alegre to Treinta y Tres, already in Uruguay and corresponds to what Delaney (1965) had called the Lagoonal Plain.

The plain has low elevations, it gently dips eastwards where broad rounded hills, near the Shield slope, yield to a succession of terraces, all of which very much dissected by the present drainage.

From the slopes of the Sudeste Mountain Range, the Atlantic watershed of the Sulriograndense Shield, crystalline rock outcrops are seen, covered by elluviums, colluviums and alluvial fans of the Serra de Tapes Formation. These deposits on the slope are interfingered, and later on, covered with sediment from the Graxaim Formation, which, as was seen, were accumulated by a system of braided channels, which, built up a broad coastal plain from large coalescing alluvial fans, fixing the materials from adjacent highlands which were undergoing cyclic changes from humid to arid climatic conditions, as mentioned by Bigarella & Andrade (1965) and Jost (1971).

Although construction began during the Tertiary, in this area the continental environment processes, which ordered this evolution, are still acting.

Several transgressive — regressive cycles, were directly and indirectly responsible for the formation of the successive terraces which embellish the more distal parts, still being reworked now in a lagoon environment. It is on these that some of the lagunary deposits of the Santa Vitória Member, Chuí Formation, occur. The main morphological features of these terraces will be described when we will deal with the Patos-Mirim Lagoonal System. This surface was cut out by watercourses, according to base level fluctuations, giving rise to broad river plains, where meandering channels (Rivers Camaquã, Piratini, Jaguarão, etc.) finally build deltas when they arrive in the Patos-Mirim Lagoon System. Along these river plains are the Guaíba Formation deposits.

LOMBAS BARRIER

The Lombas Barrier, which was given this name by Jost (1971), is a long strip from Northeast to Southwest, constituted by sandy deposits, which extends from the West of Barros Lagoon to the county of Barra do Ribeiro, on the West coast of the Patos Lagoon, passing along Itapoã Peninsula, south of Porto Alegre.

It is characterized as a group of rounded hills, with heights even above 100 meters, as occurs in the Coxilha das Lombas region, where they are very well developed.

According to Jost (1971), Villwock (1972) the Lombas Barrier grew from a sandy spit and barrier island system, established in the region during a Pleistocene transgression. Over the transgressive deposits of the Taim Member, Chuí Formation, along the coastline of that period, accumulations occurred of huge aeolian deposits which also covered part of the Porto Alegre-Viamão highlands, and further south, the Graxaim and Serra de Tapes Formation deposits on the Inner Alluvial Plain. These aeolian deposits constitute the Itapoã Formation, which has its type — section in this region.

During its growth, the Lombas Barrier isolated two lagunary bodies. One, Northeast of the Porto Alegre-Viamão highlands, evolved into what is now called the Chico Lomã Swamp, and the other, to the west, invading the Central Depression, called Porto Alegre Basin by Jost (1971), which evolved, forming what is now the Guaíba River. It is in the Porto Alegre Basin, which includes what Delaney (1965) called Guaíba Estuary Lowlands, that Jost (1971) defined the Guaíba Formation composed of river deposits, in which there are interbedded marine strata in the distal parts. Since its was formed, this basin received the detritic load brought down from the Plateau and the Shield by rivers, and reaching it through the Central Depression. Now, the construction of a delta facing the city of Porto Alegre can be observed. Although this delta receives clastics from the Gravataí, Sinos, Caí and Jacuí rivers, it is called the Jacuí Delta.

Geomorphological and sedimentologic detail studies of this area were presented by Cunha (1971) and Gomes (1976), the latter for the purpose of implementing the Jacuí Delta State Park, an ecological reserve project.

Besides the several river and delta features occurring in this area, Delaney (1965) described two terraces, the older one called Gravataí (12-20 meters), and a more recent, Pombas (3-5 meters), both developed on the banks of the Guaíba.

In the lagoon isolated body further northeast, geological evolution took a different course. This area, was studied in detail by Villwock et alii (1980), and Loss et alii (1982), began developing from a basin which evolved to a lagoon and finally was isolated from the ocean by the full closure of the barrier, managed by the litoral processes acting there. The elevation of the lagoon level thus formed, allowed it to flow westwards through a narrow channel excavated in sedimentary terrain of the Paraná Basin sequences, creating what is now the Gravataí River (Negros Pass).

The area was gradually filled by lagoonal and later on by paludal deposits from which large peat deposits developed during Holocene, as described by Villwock et alii (1980).

North of the Guaíba-Gravataí Lagoonal system, on the Southern slope of the Plateau, are the previously described Gravataí Formation deposits. They are large alluvial fans which cover the Paraná Basin Formations and interfinger the deposits of Lombas Barrier and Guaíba-Gravataí Lagoon Formation. Processes responsible for the formation of these alluvial fans are still active on the eastern slope of the Plateau, and were described in detail by Gomes (1976).

COMPLEX MULTIPLE BARRIER

The narrow earth strip extending northwards between the Plateau slope and the Atlantic Ocean, which further south isolates the Patos-Mirim Lagoon complex from the Ocean, was called Sandy Littoral Plain by Delaney (1965).

The geomorphological data of this region, published by Jost (1971), Soliani (1973), Zeltzer (1975), Godolphim (1975), Jost & Soliani (1976), confirm the ideas of Villwock (1972), who described this region as a complex multiple barrier, as defined by Curray et alii (1969).

Starting from the foot of Coxilhas das Lombas, towards the Atlantic Ocean, a succession of elongated, rather flattened, ridges and depressions are seen, which constitute the most characteristic morphological aspects of the barrier.

The first depression, the broadest, is occupied by the Patos-Mirim Lagoon system, and the Barros Lagoon also is part of it. Since it is important for the geomorphological view of the coastal plain, it will be described further on.

It was isolated starting with the construction of a sandy spit and barrier island system, remnants of which are still found on the littoral plain, like a sandy ridge built from marine beach sediments, covered by aeolian deposits and ancient littoral dunes.

Further east, a second elongated depression but narrower than the first, was occupied by swamps and peat bogs reflecting old lagoons which are the result of silting up occurring in an ancient lagoon system which developed in the region. The swamps of Cidreira, Grande and Cacimbas, which lies east of Palmares do Sul, belongs to this lagoonal system. The lagoons of Flores and Caiuá, which lies south of Rio Grande and the Depression in which the Chuf Creek flows, east of Santa Vitória do Palmar, also seem to belong to this system.

The sandy barrier which isolated this ancient lagoonal system also includes marine beach deposits covered by littoral dunes. As it was seen earlier, the sediments accumulated in this multiple barrier system built up by littoral processes related to wind action, waves and currents during the transgression and regression episodes occurring in the Pleistocene, are part of the Chuf Formation, Santa Vitória Member, the lagoonal ones, Taim Member, the marine ones, and Itapoã Formation the aeolian ones.

A marked feature, along the whole littoral Sandy Plain, is the fall line which marks the inner boundary of a new lagoonal depression. This fall line which is even interpreted by Delaney (1961) as a fault scarp, and is contradicted by Ab'Saber (apud, Delaney, 1961), marks the maximum boundary of the great Holocene transgression approximately 5000 years B.P. The regressive phase which followed, allowed one more barrier to build up, isolating the new lagoonal system.

This lagoonal system consists of necklace of coastal lagoons which evolved by segmentation, controlled by the regional wind regimen, blowing mainly from the Northeast. Itapeva, Quadros, Tramandaí, Fortaleza, Cidreira, Porteira lagoons are, among others, which Delaney called cordiform, make up a system interlinked by channels which go as far as developing small tidal deltas, and are joined to the Atlantic Ocean through Tramandaí Channel. Further south at the level of Mostardas is Peixe Lagoon, with a temporary outlet to the sea. South of Rio Grande the Mangueira Lagoon, is the most developed of this system. More details on the physiography and sedimentation of these water bodies can be found in

Vassão (1952) Delaney (1960), Motta (1967), Villwock (1972), Lira et alii (1974) and Alvarez (1979).

The last barrier, which is Holocene in age, comprises a group of well preserved regressive beach ridges found between Capão da Canoa and Torres, and further south in Rio Grande County, where they were described by Godolphim (1976). For the rest of the coastline, these sandy beach deposits were completely reworked by wind action, resulting in dune fields with a variable width of 2 to 8 km, where barchans, transversal barchan chains and transversal dunes over 30 m high occur.

The littoral strip which extends between the dune field and the Atlantic Ocean is very narrow, (40 meters overage), and presents well developed backshores and foreshores. The backshores are almost always decorated by foredunes, whereas the beach cusps are common in the foreshore.

Martins (1967) described in detail the textural, structural and morphological features of this sandy sediments strip and Villwock and Martins (1972) and Martins et alii (1979) described the muddy deposits which occasionally accumulate in the littoral strip near the Rio Grande bar.

It is also from this last barrier that Silva (1976) and Villwock et alii (1979) described large accumulations of titanium and zirconium-bearing black sands.

PATOS-MIRIM LAGOON SYSTEM

This system began to be isolated from the Atlantic Ocean during the Pleistocene, when the above described large complex multiple barrier built up. Part of it, from North to South, are the Barros Lagoon, a broad area occupied by lagoon and paludal deposits, the Pachecos Swamp, Casamento Lagoon, Patos Lagoon, São Gonçalo Channel Plain and Mirim Lagoon.

The main characteristics of this system are obvious when Patos Lagoon and marginal areas are described, once this is its most important feature.

The main physiographic aspects of Patos Lagoon have been described by Delaney (1965), Villwock et alii (1972), Villwock (1972), Herz (1977), Calliari (1980), and Alvarez et alii (1981).

About 11,000 square km in area, 250 km long and an average width of 60 km, linked to the Atlantic Ocean by a single permanent outflow channel, the Lagoa dos Patos is a lagoon which behaves essentially like an estuarine system, as according to Bird (1968).

Bathymetrics, although gentle, is diversified. Most of the banks are shallow, between 0.5 and 1 meter, and the deepest parts are confined to the central zones, 7 to 8 meters, and along the Rio Grande Channel, where it varies from 10 to 15 meters. In cross sections, the western bank has a gentler slope than the eastern.

Water circulation is not much influenced by the diurnal ocean tides, mostly felt in Rio Grande, where the mean amplitude is about 0,47 m.

However, appreciable changes in water level are a result of flow variations in the tributaries which drain a surface of approximately 175,000 square km, thus exposed to different rainfall regimens.

River flows develop currents which project into the lagoon, and, during the rainy periods, their effect is felt over long reaches.

The wind regimen is equally responsible for large variations in water level, resulting in level differences of up to 2 meters between the north and south limits of the lagoon.

Under these conditions are influenced by the lagoon banks configuration, however they are not effective as far as erosion and sediment transport through the lagoon is concerned. In general they are responsible only for keeping fine material, brought in by rivers suspended, distributing it throughout the sedimentation basin and taking it to the extreme South, where increased salinity helps deposit it by flocculation processes. Measurement of suspended materials presented by Alvarez et alii (1981) confirm this behaviour. The largest concentrations are found in river influence zones, values between 75.5 and 40.5 mg/l. These values diminish along the lagoon, 32.00 to 0.7 mg/l, and increase again in the southern, estuarine zone, especially at greater depths, where flocculation is effective at the surface of water the amount of suspensions varies between 9.0 and 1.8 mg/l, while in depth values of 32.0 to 1.2 mg/l have been detected.

On the other hand, it is undeniable that wind-generated wave action plays a prominent role in the erosion/deposition balance which causes the lagoon bank configuration.

In the coastal region of Rio Grande do Sul, prevailing winds blow from NE, and in this direction the Patos Lagoon banks show a succession of broad bays and sandy spits resulting from the action of waves and littoral currents they generate, trying to direct the beaches at right angles to the direction of prevailing winds.

In this way it can be stated that the Patos Lagoon is undergoing a real segmentation process through the formation of sandy spits, according to the mechanisms described by Zenkovich (1967).

The water circulation mechanism described briefly above, is responsible for variations in salinity which are observed there. Data on this subject can be found in Closs (1953), Closs & Medeiros (1965), Closs & Madeira (1968), Calliari (1980) and Alvarez et alii (1981).

Usually it is fresh water and only in the southernmost parts are increasing salinity values found, and then they present poli, meso and oligohaline behaviour.

Water temperature is between a minimum of 13°C in Winter and a maximum of 27°C in Summer. From May to September the temperature is below 20°C, and from October to April above 20°C.

Besides the coastline tracing and lagoon bank sculpting agents described above, other factors have exerted considerable influence over the establishing of the present configuration of the whole area covered by the Patos-Mirim system. These

factors are related to slow and periodical changes of the regional base level, which were translated into transgressions and regressions of the lagoon banks, as a direct consequence of fluctuating sea levels which conditioned the growth of the Complex Multiple Barrier.

Actually, besides the surface which is now taken up by the Grande Swamp, where the Santa Vitória Member sediments build a slightly eastward-dipping surface, with heights ranging from 13 to 4 m, 7 m on the average, on the West bank, cut into the Inner Alluvial Plain, there is a terrace, heights ranging from 15 to 9 m, internally limited by a very attenuated scarp. Both seem to mark the maximum level of transgression which started the lagoon system formation here described.

A lot more visible and better preserved is the large lagoon terrace which surrounds Patos and Mirim Lagoon, with heights ranging from 5 to 2 meters, and a width of 1 to 12 km. Without inner boundaries it is marked by an erosion scarp or by sandy cordons which delineate former spits or curved spurs. On the surface are seen beach ridges and older lagoons, occupied by swamps and peat deposits. It is on this surface that the São Gonçalo channel meanders, in the area which connects Patos and Mirim Lagoons, reworking lagoon sediments and accumulating meandering river deposits, like meander bars, natural dikes, crevasse splay deposits, flood plain deposits, and filled older channels, as described by Villwock, (1982).

The outer limit of the lagoon terrace which has just been described is marked by the scarp of a more recent terrace where heights range from 1 to 2 meters. In some places the inner boundary is marked by beach ridges.

The sediments which build up these lagoon terraces are not much different from the formations which build up the marginal areas.

The bottom sediments of the lagoon system, and particularly of Patos Lagoon, were studied by Martins (1963), Martins (1966), and Martins & Gamermann (1967), Cunha (1971) Martins (1971), Villwock et alii (1972), Villwock (1977), Calliari (1980) and Alvarez et alii (1982).

Usually, when the faciological variation is analyzed, based on the sand, silt and clay contents, it is seen that the bottom sediments of Patos Lagoon present a distribution which is not much different from the standards observed in other lagoon bodies such as those described by Nichols (1964), Rusnak (1960) and Phleger (1969).

The sandy facies occupy the marginal, shallower areas (0 – 4 m). The silty facies are distributed throughout the more central and deeper areas (4 – 8 m), and occur also along the Guaíba channels and the access to the Port of Rio Grande. Clayey facies constitute small occurrences amidst silty facies, in the deeper parts, besides a broad zone placed in front of the Camaquã River Delta. Mixed sandy-silty-clayey facies are restricted to the various basins in the lower middle portion of the lagoon.

The analysis of the coarse fraction of these sediments shows that in sandy facies, quartz and fragments of mollusk shells are the essential components. In

greater quantities are heavy minerals, carbonaceous materials, mica, Foraminifera, limonitic concretions and rock fragments.

In silty and clayey facies, shell and quartz fragments predominate and the other components occur in very small ratios.

The highest wood fragment contents are found near the Camaquã River Delta, and the same is true for the quantity of heavy minerals.

As far as clayey minerals present in muddy facies are concerned, in order of abundance we have smectite, kaolinite, interstratified illite-smectite and chlorite. It is a detritic combination, inherited from the source areas as established by Villwock et alii (1972).

The source of lagoon sediments consists partly of formations which make up its banks, constantly reworked by wave action, partly of clastic material brought by the rivers which drain the highlands of the Sulriograndense Shield and the Plateau.

CONTINENTAL SHELF

Considering the geological mechanisms which cause the evolution of the coastal region, the emerged plain and the adjacent continental shelf constitute a single geological unit without any structural discontinuities. The coastline which now separates these two broad environmental domains always takes up a transient physical position, depending on sea level variations. Thus, it can be deduced that a good knowledge of the geology of the emerged part of the coastal region permits a forecast of the geological behaviour of the adjacent continental shelf.

It presents a quite regular and homogeneous morphology. The width is 150 km, on the average, and the slope is 1.3 to 1.4 m/km, up to a depth of 170 m, when it dips towards the continental slope.

The sediments which cover the bottom of the continental shelf as observed in Martins et alii (1967), Martins et alii (1972), Martins et alii (1973) and Martins and Urien (1977) are predominantly terrigenous clastics, with some biotrititic concentrations.

The cover of the innermost part of the shelf is Sandy Facies, comprising fine, well-selected sands, similar to beach sands on the oceanic side of the multiple barrier. It occurs in the form of a strip which more or less follows the 40 m isobaths, interrupted only at the mouth of the Rio Grande Channel, where there are sandy-silty and sandy-clayey deposits of the Patos Facies, and further south by a tongue of sandy-muddy sediments of the Platine Facies, and also by some gravel and bioclastic sand areas, formed by shells and/or fragments of mollusk shells of the Biotrititic Facies.

On the medium and outer shelf there is a Transitional Facies composed of silty and clayey sands, sandy and clayey silts with variable proportions of biotritus, all showing a clear transition between the sandy facies and the slope facies which extends into the sea from the 100 meter isobaths onwards, constituted by clayey silts and silty clays.

The Platine and Patos facies are the result of recent sedimentation and signify a present contribution of clastics coming from the La Plata River and Patos Lagoon. The other facies are relicts, sometimes partly changed, palimpsestic, an ancient sedimentation which built an ample coastal plain, with deltas, barrier islands, lagoons, all of them submerged since the great Holocene transgression.

Heavy mineral studied by Tomazelli (1978 & 1979) showed the main lines of origin and direction of supply of materials, which constitute this sedimentary cover. Four mineralogical provinces were recognized:

1) the Inner Riograndense Province, with high maturity, caused by the reworking of coastal sands whose primary source were the Sulriograndense Shield rocks; 2) the Outer Riograndense Province, which is relatively immature, coming from the Highlands of the Shield and Plateau, deposited by rivers which reached the shelf before the Multiple Barrier was erected; 3) the Patos Province constituted by recent deposits, coming through the Patos Lagoon, from the Shield and the Plateau; 4) the Platine Province constituted by deposits which accumulated by paleodrainage connected to the La Plata River, which, in spite of having been reworked by waves and currents during the Holocene transgression, retained its geographic position.

Gamboa et alii (1973), studying the groups of sediment clay minerals in this same area had arrived at similar conclusions as to source areas.

Studies on the paleogeographic evolution of the continental margin of this area were made by Martins & Urien (1979) and Urien et alii (1980a, 1980b).

PALEOGEOGRAPHIC EVOLUTION

Although they are insufficient to prepare a detailed scheme of its geological evolution, the data gathered up to the present allow one to establish important events of the paleogeographic evolution this area.

Actually, several attempts have been made. They began with Smith (1901), Backheuser (1918), Gomes and Ab'Saber (1969), continued with Jost (1971), Villwock (1972), Soliani (1973), Jost et alii (1975), Zeltzer (1975), Godolphim (1975), Jost & Soliani (1976), Jost & Herz (1976), Villwock (1977), all of them establishing their paleogeographic schemes on the morphological features of the emerged areas. Martins and Urien (1979) and Urien et alii (1980a, 1980b) prepared theirs, based on the submerged morphological features and the characteristics of the sedimentary deposits which accumulated on the continental shelf and adjacent slope.

The greatest problem which still persists, in setting up the various stages of paleogeographic evolution, lies in the scarcity of geochronological data, and in applying the eustatic variation curves proposed by Fairbridge (1961), which are inadequate for this region. That was the case of Villwock (1972) who, despite correct geomorphological interpretation, impaired his scheme, since, besides

adopting Fairbridge's chrv, he based his work on incorrect data regarding the paleontological chronology.

It became obvious that sedimentation and morphological edification of the area studied was controlled by the succession of transgressive and regressive events, and, in this sense, after the big Miocene transgression, all successive cycles left their marks imprinted on the surface of the coastal plain and continental shelf. From them the evolution scheme presented in Fig. 5 e 6.

Here is seen a tentative paleogeographic configuration at the time of the following episodes:

- a — During Pliocene regression, when the large deltaic fans, linked to a system of braided channels, covered wide areas with coarse clastic deposits which were part of the Graxaim Formation.
- b — After the first Pleistocene (Lower Pleistocene) transgression-regression cycle, the Lombas Barrier developed, isolating the Guaíba-Gravataí Lagoon System.
- c — After the second Pleistocene (Middle Pleistocene) transgression-regression cycle, when the construction of the Multiple Barrier began, which then begins to isolate the Patos-Mirim Lagoon System.
- d — After the third Pleistocene (Upper Pleistocene) transgression-regression cycle, when the Multiple Barrier continued to grow (adding the second barrier) and later the alluviation of the Patos-Mirim Lagoon System, allowing the formation of an enormous coastal plain which extended until the present 100-meter isobath, which was the sea-level at the time, ± 14.000 years B.P., according to Martins and Urien (1979).
- e — During the high point of Holocene transgression, which caused the formation of a sea cliff at the Multiple Barrier and the abrasion of the Holocene lagoon terrace in the Patos-Mirim System.
- f — The present situation, after the Holocene regression which allowed adding a third barrier to the Multiple Barrier, forming Mangueira Lagoon and the necklace of Lagoons in the northern part of the coastal plain. Also the Holocene terrace which constitutes the São Gonçalo alluvial plain and the greater part of the surface of the spits which decorate the banks of Patos and Mirim Lagoons, emerged during that regression.

Although this is a brief description, the tentatively depicted evolution is not much different from what has been presented for other sections of the Brazilian coast, especially Dominguez et alii (1981).

However, in none of the areas studied in detail along the Brazilian coast, such as São Paulo (Martin et alii, 1979) and Bahia (Vilas Boas et alii, 1979), are the various evolutionary stages of the Pleistocene as well portrayed as here in the Coastal Plain of Rio Grande do Sul. It is certain that the continued geological mapping work in this region will add important data to what has been written describing the geological evolution of the Cenozoic terrains which make up significant sections of the Brazilian coast.

ASSOCIATED MINERAL RESOURCES

Development of coastal areas usually includes increasing agricultural and fishing activities, building ports cities and highways, industrialization and recreational and touristic facilities. For most of these activities, according to Becker (1976), a number of natural resources must be brought to bear.

When they are present in the region, as is often the case with sand, gravel, limestone, fertilizers, water, their use must be planned so as to not interfere in other local uses such as recreation, tourism and urban expansion.

Since the occurrence of mineral resources depends directly on the geological history of the coastal region and adjacent highlands, data of this kind is essential for any type of management planning in these areas.

Therefore, characterizing the Coastal Province of Rio Grande do Sul with terrigenous, detritic, sedimentary sequences which have accumulated in continental transitional and marine system is a way of defining the potencial of mineral resources. They will be alluvial (gravels, sands and mud) and organogenic (peats, diatomites, carbonaceous biotritus).

In fact, the alluvial plains of the main watercourses which have reached this coastal region, the terraces and lagoon beaches, the marine terraces and the aeolian deposits, have been intensively used near all urban concentrations, supplying them with building materials, except for the rock materials which can only be developed on the Shield and Plateau slopes, where are also found the alluviums and colluviums used in building highways.

Sands for the glass industry have been exploited along several lagoon beaches.

Despite the poor carbonaceous accumulations seen there, accumulations of mollusk shells, "shell mounds", are known, both along the Multiple Barrier (Palmares, Shangrilá Mostardas, Tavares and Estreito) and on the banks of Mirim Lagoon, (Alegre Point and Latinos Point). However the largest accumulations of biotrititic carbonates are found on the Continental shelf. They have been described by Figueiredo (1975) Correa & Ponzi (1975 and 1979).

Diatomite occurrences were mentioned by Figueiredo and Salgado (1964), Delaney (1969) and Villwock et alii (1980).

Large peat deposits taking up paludal zones, which have evolved from the filling in of ancient coastal lagoons, were described by Villwock et alii (1980). Their use as source of alternative energy and soil reconditioner for agricultural purposes is discussed in Villwock et alii (1982).

Beach placers containing high concentrations of ilmenite, rutile, magnetite, and zircon occur along the present coastline and in some sections of aeolian accumulation in the Multiple Barrier. They were studied by Silva (1976), Villwock et alii (1977 and 1979), Villwock et alii (1979) and Loss & Dehnhardt (1982).

One must not forget to mention the large coal deposits which are known in the substratum of the Northeast region of the coastal plain, the Rio Bonito

Formation, a sedimentary sequence of the Paraná Basin, whose characteristics are presented by Bortoluzzi et alii (1960), and Camozzato et alii (1982).

Water supply for small population groups has been obtained from aquifers stored in sandy formations. The quality is not always good.

Rivers and lagoon bodies supply water to the large urban areas and industrial centers, such as Porto Alegre Metropolitan Region, and the cities of Pelotas and Rio Grande, and some bathing resorts on the northern coast, such as Torres and Capão da Canoa.

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Table 1

PETROBRÁS DRILLINGS IN THE EMERGED PORTION OF PELOTAS BASIN					
Well	Depth	Site	County	Latitude S	Longitude W
2-PJ-1-RS	175,20m	Ponta do Juncal	Jaguarão	32°36'10"	53°09'10"
2-CA-1-RS	320,20m	Curral Alto	Sta. Vitória do Palmar	32°55'34"	52°44'47"
2-CI-1-RS	572,20m	Cassino	Rio Grande	32°12'00"	52°10'30"
2-PN-1-RS	267,20m	Povo Novo	Rio Grande	31°57'00"	52°17'00"
2-GA-1-RS	165,15m	Graxaim	Camaquã	31°01'40"	51°33'46"
2-MO-1-RS	1570,20m	Mostardas	Mostardas	31°14'45"	50°54'18"
2-PS-1-RS	414,20m	Palmares do Sul	Osório	30°10'39"	50°29'30"

Fig. 1

Fig.4

RIO GRANDE DO SUL COASTAL PROVINCE

Fig.5 Paleogeographic Evolution of Rio Grande do Sul - Coastal Plain
(PRELIMINAR SKETCH)

Fig.6 D- PLEISTOCENE TRANSGRESSION - REGRESSION IIII

E- HOLOCENE TRANSGRESSION (± 5500 BP)

F- HOLOCENE REGRESSION (today)