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EVOLUTION OF THE SEMI-ENCLOSED BASINS AND SURROUNDING COASTAL PLAINS ADJACENT TO THE PAMPEAN REGION, ARGENTINA

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Abstract. The coastal plains adjacent to the Pampean region in eastern Argentina evolved during the Holocene in response to interaction between sea level fluctuations and different littoral dynamic factors in such a way that several sedimentary environments developed. Evolutionary stages can be synthesised in three periods: 1) the post-LGM transgression, when landward migrating coastal barriers extended on the present shelf under the effect of a dominant northward littoral drift; 2) the last stages of the transgression (between 8000 and 6000 years BP), when the rising sea flooded the Alto Marítimo (a pre-Holocene positive morphological feature which in previous times separated the course of the de la Plata river from the open sea), resulting in a new coastal configuration in which the presence of two headlands, Punta Piedras (in the north) and Villa Gesell (in the south), influenced the coastal processes so changing the original regional northward littoral drift into cell-type circulation systems; 3) between 6000 years BP and the present, when progradation processes characterised by barriers and beach ridges development dominated as a result of the sea level fall and an excess of sediment supply. As a result, coastal semi-enclosed basins located in between the headlands, such as Samborombón bay and Mar Chiquita lagoon, became the main depocenters where low-energy conditions (coastal lagoons, tidal flats and marshes) prevailed due to its isolation from the open-sea by the barriers and ridges. Interaction between southward migration of coastal environments associated to the northern headland and northward migration of those related to the southern headland was a very important process in shaping the present morphology of the area.

Key words: coastal plains, coastal evolution, semi-enclosed basins, post-LGM transgression, Holocene, Argentina.

INTRODUCTION

The coastal plains adjacent to the Pampean region in eastern Argentina (between 34–38°S and 57–58°W, covering an area of around 7,600 km^2) constitute a very interesting site for studying the Holocene sedimentary records and its generating processes, since morphological, lithological, oceanographic, climatic, eustatic and dynamic characteristics favoured a large sediment supply and deposition in several coastal environments developed in very extensive regions and allowed its almost complete preservation in the stratigraphic sequences. Coastal irregularities show semi-enclosed environments such as Samborombón bay and Mar Chiquita lagoon (Fig. 1), which during its evolutionary history trapped most of the sediments transported along and across the shore.

The Cenozoic sequences in the region have been studied since as early as the end of the XIX century from the morphological and stratigraphical viewpoints, although since the middle 1970's research was aimed at describing evolutionary aspects related to coastal dynamic. Particularly, the Group of Marine Geology and Geophysics from the Argentina Hydrographic Service has carried out detailed surface and subsurface geological surveys that included the drilling of 42 boreholes up to 27 metres deep performed with a drilling rig, as well as around other 200 no deeper than 6 metres with a hand-sampling device. Most of the results were already published (Parker, 1979, 1980; Parker, Violante, 1982, 1993; Violante, 1992; Violante, Parker, 1992; Violante *et al*., 2001). A great source of information was a hydrogeological project undertaken in the late 1980's (Parker , Violante, 1990, 1991) whose objective was exploration for new water resources in the country's most populated touristic area (beach resorts extended along more than 300 km in the eastern coast of the Province of Buenos Aires between Punta Rasa and Necochea, Fig. 1). The region is also important since Samborombón bay was selected as a Ramsar Site in 1997 and Mar Chiquita lagoon is an UNESCO

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Fig. 1. Location map

Biosphere Reserve, whereas other areas have been declared by Nacional, Provincial and County laws as protected wildlife reserves, biological stations and intangible areas.

The compilation of all the above geological information along with the information included in the available bibliography from different sectors of the area published by other authors (Ameghino, 1880; Frenguelli, 1950; Fidalgo *et al*., 1973; Fidalgo, 1979; Schnack, Gardenal, 1979; Schnack *et al*., 1980, 1982; Fidalgo *et al*., 1981; Fasano *et al*., 1982; Fidalgo, Martínez, 1983; Gómez *et al*., 1985, 1987; Dangavs, 1988; Weiler, González, 1988; Codignotto, Aguirre, 1993; Aguirre, 1993, 1995; Aguirre, Whatley, 1995; Isla *et al*., 1996; Bértola *et al*., 1998; Prieto *et al*., 1998) allowed to elaborate a detailed picture of the Holocene and to describe the coastal environments and its dynamics as well as the regional evolution, which is the aim of the present work.

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GEOMORPHOLOGICAL SETTING AND PHYSIOGRAPHY

The area is located in the coastal region surrounding the northernmost part of the Argentina continental shelf, close to the de la Plata river mouth (Fig. 1). From the coastal dynamic viewpoint it belongs to a low-energy and microtidal setting where oceanic conditions dominate, although fluvial influence is highly significant in the Samborombón bay. The northern sector surrounding the bay is a tide-dominated environment, whereas the oceanic coasts located south are wave-dominated.

The area is a part of the geological province named "Salado basin" (Fig. 2), which is laterally limited by the Precambrian blocks of Uruguay and Tandilia (both belonging to the Río de la Plata craton; Dalla Salda *et al*., 1988). The basin is filled with late-Jurassic to Quaternary continental and marine sediments. Several minor surface features associated to the basin geology and structure can be recognised, including two positive: Punta Piedras–Alto Marítimo and Villa Gesell headlands, and three negative ones: the de la Plata river, the Samborombón bay (the most depressed area in the centre of the basin) and the Mar Chiquita depression.

Despite these differences, the morphology of the area, that resulted from the last stages of the regional evolution, displays two main features: the Pampean terrace and the coastal plains.

Pampean terrace is the surface higher than 5 m above present level (exceptionally reaching 10 to 15 m in its marginal areas) which was not affected by the postglacial transgression. It is composed of Plio-Pleistocene sediments and its eastern border is quite irregular, marked by a low cliff not higher than 1 or 2 m which represents the position of the shoreline at the maximum sea level advance during the climax of the transgressive event 6000 years ago.

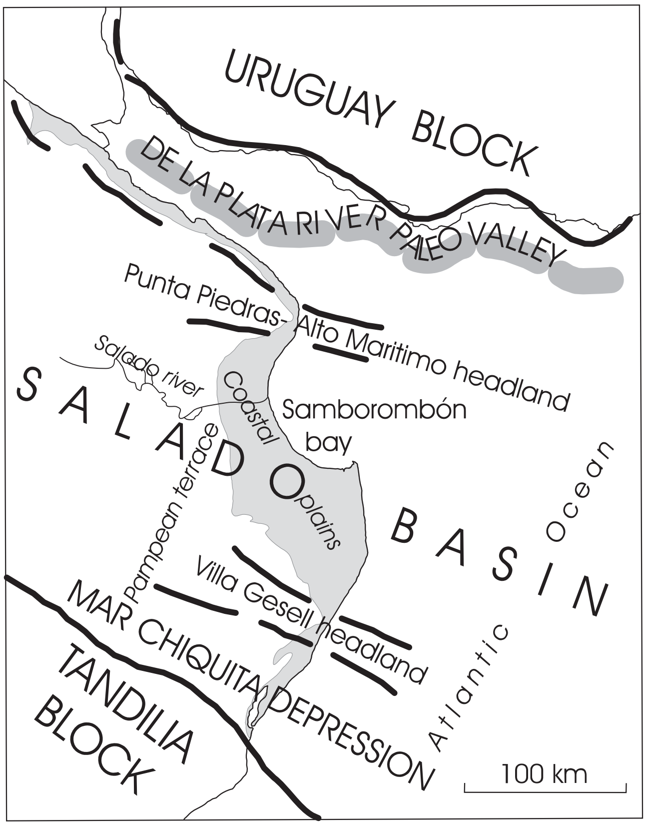

Fig. 2. Regional geomorphological setting

Coastal plains constitute a surface formed by the Holocene coastal clastic wedge which includes both the late transgressive and the following regressive facies. Relief is very low, not higher than 2–3 m above sea level, except where coastal sand dunes up to 30–40 m high are present. Around the Samborombón bay the coastal plain is directly connected to the sea through low-lying brackish-water marshes and tidal flats, whereas in San Antonio cape and areas located further south, including the sector around Mar Chiquita lagoon, a beach-dune system extends all along the coast (Figs. 3, 4).

SHORELINE FEATURES

Irregularities of the shoreline show the following coastal features (Fig. 3):

Punta Piedras is a prominent feature that represents the place where the Pampean terrace is closest to the shoreline, reaching 13 m above sea level. There, Pleistocene consolidated shelly sands and loess-like deposits outcrop in the coastal cliffs as well as in the subaqueous abrassion platform.

Samborombón bay is a semicircular shallow water body 100 km long at its mouth and 40 km wide with a maximum water depth of 10 m, surrounded by a low-lying coastal plain. The bay is located at the mouth of the estuarine-deltaic environment of the de la Plata river (Fig. 1), on the western side of the maximum saline gradient zone where mixing of marine and fresh waters originates a turbidity maximum resulting from processes of clay flocculation and settling (Cavallotto, 2002).

San Antonio cape is a stretch of coast 62 km long oriented in a north-south direction. It is characterised by a sandy beach--coastal dunes system around 2–3 km wide reaching a maximum altitude of 20–30 metres. Behind the dunes, low-lying terrains extend over a very large surface. Its northern and southern extremes are respectively Punta Rasa and Punta Médanos.

Coast between Punta Médanos and Mar Chiquita lagoon is a stretch of coast 120 km long oriented in a northeast-southwest direction. A similar beach-coastal dunes systems as in San Antonio cape developed here, although it is wider (up to 4 km) and higher (up to 40 m). Mar Chiquita lagoon is the only coastal lagoon linked to a littoral barrier presently active in Argentina; it covers an area of 46 km^2 and its maximum water depth is less than 3 m.

SEDIMENTARY ENVIRONMENTS

Holocene sedimentary environments preserved on the surface and subsurface of the coastal plains have been described with various degrees of accuracy during more than 100 years (see bibliography cited above). But in the last three decades

Fig. 3. Satellite image of the working area and localities mentioned in the text

thorough studies on the stratigraphy, lateral and vertical facies distribution, sea-level fluctuations and faunal content have been undertaken in specific study areas as well as on a more regional scale and provided valuable results in terms of understanding most of the evolutionary aspects. All these aspects together are considered in this paper.

The Holocene deposits in the Buenos Aires province coastal plains, which were included in the post-glacial depositional sequence (Violante *et al.*,1992, recently updated by Violante, Parker, 2000 and in press), constitute a sedimentary sequence where a lower transgressive and an upper high-stand units (or system tracks) have been recognised. The boundary between them is regarded as the sedimentation surface at the time when the sea level reached its maximum height (the flooding surface). Figure 5 shows several typical cross--sections of the area.

Several authors have discussed the moment of the transgressive maximum in the region (Parker, 1980; Schnack *et al.*, 1982; Weiler, González, 1988; Violante, 1992; Aguirre, Whatley, 1995). The most recent information comes from the paper by Cavallotto *et al.* (1995, later updated by Cavallotto *et al.*, 1999 and in press) who, although working in the southern coastal plain of the de la Plata river, built the latest and most reliable regional sea level curve based on a more sophisticated approach to the available radiocarbon datings, which can be extended onto the study area. According to this curve, the highest sea level reached +6 metres above the present one 6000 years ago, but incidence of tides and storms waves must be deduced. The position of the sedimentological records of marshes (resulting exclusively from high tides without storm influence), as well as the position of the base of the beach ridges reveal a maximum sea level position of around 4–4.5 m.

Transgressive unit is composed of several sedimentary environments deposited during the last stages of the eustatic rise until the time when sea level reached its maximum height. The sedimentary environments in the coastal plains are: littoral barriers, coastal lagoons and tidal flats/marshes (Fig. 5).

Littoral barriers constitute an elongated body of sands (around 6 km wide and 6 to 10 m thick) extended all along the area between Punta Rasa and Mar Chiquita lagoon. Facies relationships, geometry and sedimentary structures are typical of barriers deposits (Violante, 1992). They are formed by yellow to yellowish brown sands (grain size variable from coarse to fine) with shell fragments and pebbles, that also contain beach-rocks pieces (Parker, 1979, 1980). Fine sandy sediments laterally associated to the barriers extend inlands as ancient beach deposits around the outcropping Pleistocene substrate (Fig. 4).

Coastal lagoons develop on the backbarriers side covering the extensive surface that was flooded during the maximum of the transgression, with a maximum thickness of 8–10 metres (Fig. 5). They are composed of very fine dark olive grey and black sands, silts and clays bearing shell fragments, vegetal debris and a high content of organic matter (Fidalgo *et al.*, 1973; Parker, 1979, 1980; Violante, 1992; Violante *et al.*, 2001). Aguirre and Whatley (1995) and Laprida (1998) described the faunistic and palynological content. According to them, molluscs indicate relatively cold waters, whereas foraminifers and ostracods comprise inner shelf species, particularly in marginal waters in a low-energy, semi-enclosed environment partially connected to the open sea. Sedimentary structures reveal a strong tidal action and reduced wave activity. Waters were temperate, eu- to polyhaline, well oxygenated and rich in nutrients. Some fluvial action is evidenced by the presence of vegetal debris. A preliminary pollen analysis indicates the presence of halophytes vegetation revealing a colder, dryer and more windy climate as compared to the present climatic conditions. A ^{14}C dating obtained for the unit (Fidalgo *et al.*, 1981) yielded an age of 7030 yrs. BP.

Tidal flats and marshes appear in protected places at the innermost edges of the coastal lagoon deposits up to 2 metres thick. They are built of yellowish green clays and muddy sands with bivalve shells. In the vicinity of the Mar Chiquita lagoon, molluscs shells from brackish environment were found in living position with articulated valves, whereas gastropods re-

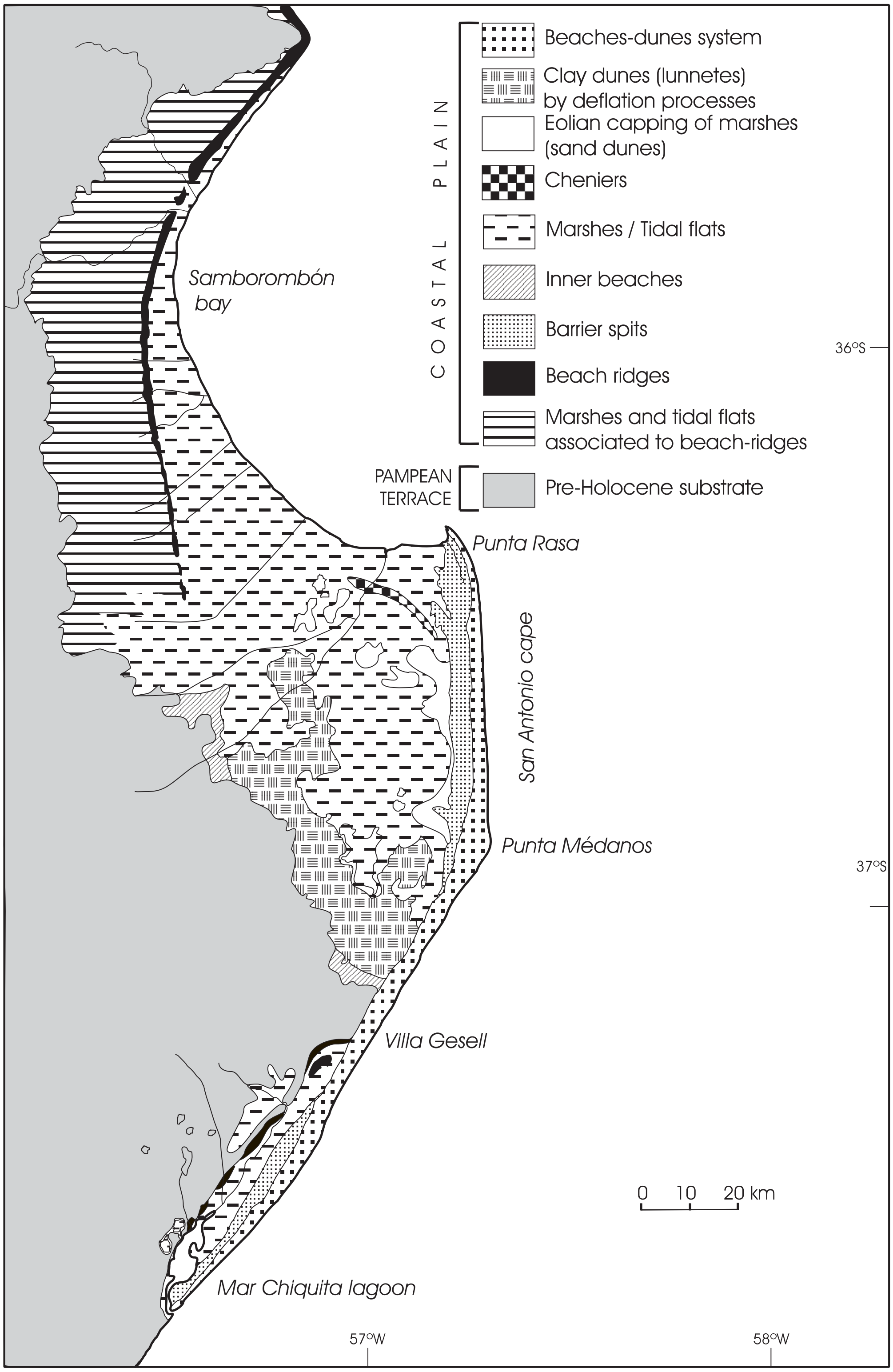

Fig. 4. Geomorphological map of the working area

mains from brackish to fresh-waters are also present (Violante, 1992).

High-stand unit is represented by the sedimentary facies deposited during the sea level fall which occurred from 6000 years BP to the present. Several environments can be recognised: spit barriers, beach ridges, tidal flats/marshes and dunes, which shape most of the present morphological features (Figs. 4, 5).

Spit barriers are composed of successive prograding spits attached to each other in a south-to-north direction from Punta

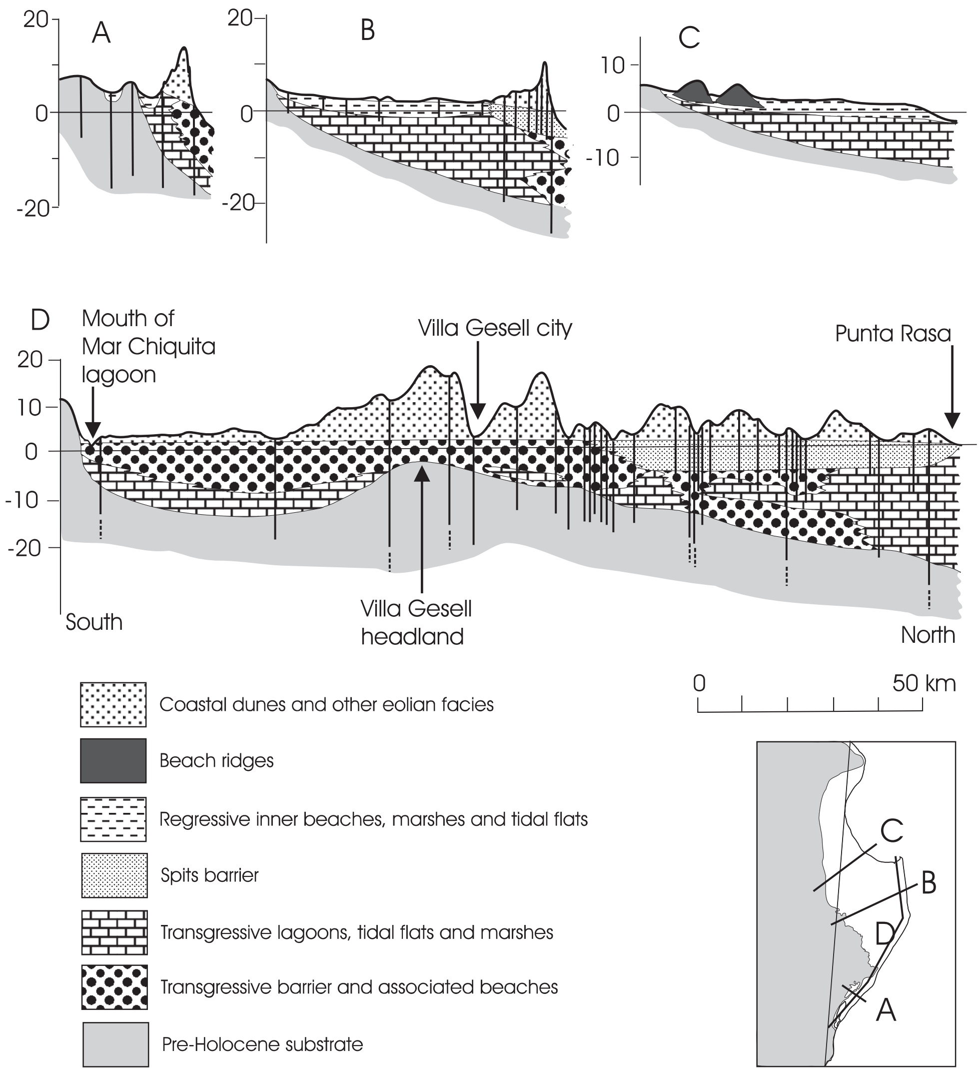

Fig. 5. Cross-sections from characteristic places. A. Near Mar Chiquita lagoon. B. San Antonio cape. C. Samborombón bay. D. South-to north cross-section along the coast

Médanos to Punta Rasa in such a way that the entire set shapes the San Antonio cape. Sediments are yellowish brown sands with abundant shells (both complete and in fragments) and gravels. Spits are also present in the area around Mar Chiquita lagoon, where they are composed of fine sands with shell fragments. Along the entire coastal area they are covered by modern sand dunes that constitute the most conspicuous features in the region (Figs. 4, 5).

Beach ridges systems develop as successive sets of ridges more or less parallel to the shoreline, with decreasing altitudes and ages towards the coast (Figs. 4, 5). A very large amount of ^{14}C datings exist for the area and are listed in the papers by Fidalgo (1979), Fidalgo *et al.* (1981), Schnack *et al.* (1982), Figini *et al.* (1984, 1990), Gómez *et al.* (1985, 1987), Codignotto *et al.* (1992), Figini (1992), Violante (1992), Violante, Parker (1992), Aguirre (1993, 1995), Codignotto, Aguirre (1993) and Figini, Carbonari (1993). Codignotto, Aguirre (1993) described the beach ridges systems around Samborombón bay, although many of their results were later discussed and reinterpreted by Violante *et al.* (2001). Three sets of beach ridges are present, the two innermost and older ones reaching +6/7 m above the present sea level yielding ^{14}C ages between 6980 and 3050 years BP, and the other at altitudes not higher than 4–5 m with ^{14}C ages between 3760 to 2540 years BP. Although many of the ^{14}C datings show decreasing ages in the south-to-north direction (from the interior of Samborombón bay towards Punta Piedras, Fig. 3), Violante *et al.* (2001) discussed the reliability of the data and interpreted them into a regional stratigraphical and morphological context. As a result, they concluded that the beach ridges prograded southward from its place of attachment to the mainland in Punta Piedras, in accordance with the model established by May and Tanner (1973) and Swift (1976). Aguirre and Whatley (1995) coincidentally mention aminoacids datings showing older ages around the same place.

Beach ridges are predominantly composed of shelly sediments included in a matrix of sands, silts and pebbles. Both, sedimentary structures (Spalletti *et al.*, 1987) and molluscs fauna (Aguirre, Whatley, 1995) indicate high-energy deposits, in the case of shell fragments with a high degree of abrasion and fragmentation, particularly near Punta Indio (few km north of Punta Piedras, Fig. 3) where shells are associated to hard bottoms (consolidated Pleistocene deposits outcrop there).

On the other hand, foraminifera and ostracods associations (Dangavs, 1988; Codignotto, Aguirre, 1993; Aguirre, Whatley, 1995; Bertels-Psotka, Laprida, 1998a, b, c; Laprida, 1998) reveal the presence, at the time of deposition, of more brackish waters (mixo- to poly-euhaline) than in present times, in an environment that varies from the upper shoreface to the foreshore. In a vertical sequence, the top of the ridges contains faunal assemblages of tidal flat to marsh, limnic and lotic environments indicative of regressive conditions. Some evidence shows high energy deposits of washover fans at the back barriers side (Bertels-Psotka, Laprida, 1998c). The faunal assemblage also indicates waters warmer-than-today, so reflecting the conditions of the hypsitermal.

Tidal flats/marshes are composed of clays, sandy clays and muds with abundant organic matter, carbonised vegetal debris and bioturbation structures, bearing shells both in living position and in fragments. These deposits are no thicker than 4 metres and were deposited in two different settings. In protected areas behind the barriers and beach ridges they formed in a semi-enclosed environment partially connected to the open sea through tidal inlets (Figs. 4, 5); very few radiocarbon datings have been obtained from the back-ridges side in the central part of the Samborombón bay yielding ages between 6150 and 5150 years BP. The molluscs, foraminifera and ostracods content (Codignotto, Aguirre 1993; Aguirre, Whatley, 1995; Bertels-Psotka, Laprida 1998a, b, c; Laprida, 1998) indicate lower energy and salinity than the adjacent barriers and beaches, as well as a vertical change to more continental facies as evidenced by the presence of lotic and fresh-water fauna at the top of the sequence.

On the other hand, on the coasts of the Samborombón bay they formed in an open environment (Figs. 4, 5). From this site Bértola *et al*. (1998) described a sequence of environments ranging from tidal flats in the intertidal areas nearest to the shoreline to low and high marshes in the supratidal areas, including some details of its morphological, sedimentological and vegetation characteristics. Around the Mar Chiquita lagoon the epifauna indicates harder and shallower bottoms than around the Samborombón bay.

Dunes on coast associated to the beaches, which extend from Punta Rasa to the Mar Chiquita lagoon, are the most conspicuous features showing the typical morphology resulting from onshore winds. But the eolian action had also affected the marshes located inland. Patches and low-rounded dunes made of fine sands developed in some places (Fig. 4) as a result of eolian transport of sediments from the coastal dunes during times of strong wind activity. On the other hand, the innermost parts of the marshes are partially covered by “clay dunes” or “lunettes” (Dangavs, 1979, 1988), formed as a result of eolian deflation processes which occurred when sediments of the old marshes disassociated from the tidal action became dry and were blown and accumulated as eolian deposits; the resulting feature is characterised by depressions (now filled with water so constituting shallow ponds) surrounded by clay dunes at the leeside.

GEOMORPHOLOGICAL EVOLUTION

Evolution of the area was established on the basis of the sequence of events as manifested through the facies interrelationships in a regional geomorphological context. ^{14}C datings were used only as a supporting information when they agreed with other geological evidences, but no interpretations have been made based exclusively on the evolutionary tendencies of radiocarbon ages.

Evolutionary stages are synthesised in Figure 6, including two moments which occurred previously to the post-glacial transgression as they were very important in the modelling of the substrate above which Holocene deposits were laid down.

LAST INTERGLACIAL MAXIMUM AND SUBSEQUENT TIMES

During the LIM (125,000 yrs. BP, oxygen isotope stage 5e) the coastal areas linked to the open sea were characterised by the development of littoral barriers and associated coastal lagoons, whereas in areas less exposed to wave activity low-energy beaches were formed (Fig. 6A). As sea level began to fall, coastal progradation occurred by development of successive littoral barrier systems formed at decreasing altitudes, which in turn, when remained unaffected by the marine action, were progressively covered by continental loess-like sediments (Fig. 6B).

POST-LAST GLACIAL MAXIMUM SEA LEVEL RISE

As the sea progressively invaded the present shelf during the post-glacial transgression, the pre-transgressive substrate was affected by coastal erosive processes giving origin to the ravinement surface which was then covered by relict sediments resulting from reworking and remobilisation of previous littoral deposits (Urien, 1967; Swift, 1968; Urien *et al*., 1979; Parker, Violante, 1982, 1993; Violante, Parker, 2000 and in press; Violante, 2002). Coastal environments were represented at that time by littoral barrier systems extended in a southwest-northeast direction formed as a result of the regional trend of northward littoral drift. The morphological feature Punta Piedras–Alto Marítimo still separated the lower course of the de la Plata river from the open sea (Fig. 2).

LAST STAGES OF THE TRANSGRESSION

At around 8000 years BP, the rising sea passed the top of the Punta Piedras–Alto Marítimo feature and hence marine waters met fluvial waters coming from the de la Plata river, thus resulting in interaction between coastal marine and fluvial processes and the consequent setting of estuarine conditions in areas previously characterised only by marine activity (Fig. 6C). At the same time, the sea level rise slowed down and hence induced a more effective erosional activity on the coastal environments which entailed big changes in littoral dynamics and morphologies.

When the sea level approached a position similar to the present one around 7000 years BP, the coastal features extended seaward, as Punta Piedras and Villa Gesell headlands (Fig. 6D), began to deeply influence littoral processes in such a way that coastal currents were forced to diverge around them so inducing the formation of a cell-type littoral circulation with development of opposite coastal systems: one of relative higher energy associated to the Villa Gesell headland and the other of relative lower energy associated to the Punta Piedras headland. Vertical growing and longshore progradation of barriers was the result of an excess in sediment supply that compensated the sea level rise, which, on the other hand, reduced the energy level on the backbarriers side so inducing infilling processes in the coastal lagoons and tidal flats.

As the sea level stabilised at 6000 years BP and the shoreline did not continue retreating, the prevailing process was the progradation of barriers and beach ridges by littoral drift around the headlands. At this stage, the shoreline associated to the Villa Gesell headland evolved towards its simplification as the headland was completely eroded and disappeared as a conspicuous coastal feature (Fig. 6E). Later on, the northeast-growing barrier was cut at its northern tip, perhaps as a result of a momentary deficit in sediment supply, and marine waters invaded the backbarrier side so giving origin to a large bay-like body (proto-Samborombón bay) where mixing of marine and fluvial waters was the main environmental characteristic. On the other hand, the barrier that grew southwestward from the headland gave origin to another smaller bay-like body, the environment preceding the Mar Chiquita lagoon.

A different picture characterised the coastal evolution around Punta Piedras where shell ridges systems evolved northwestward and southwestward of the headland, although in this case it persisted as a prominent coastal feature since littoral energy was not high enough to completely erode it and, on the other hand, the presence of the de la Plata river also helped in maintaining its shape.

FIRST STAGES OF THE REGRESSIVE EVENT

Following the still-stand at 6000 years BP the sea level began to fall. At the northern extreme of the northward-growing barrier attached to the Villa Gesell palaeo-headland (the present Punta Médanos), successive spit barriers were formed (Fig. 6F), now accommodated to a new direction of coastal simplification (with a south to north trend). Around Punta Piedras, the two sets of beach ridges still continued evolving as in previous times, although those developed to the southwest progressively changed their direction of progradation to the south.

With the ongoing fall of the sea level, as the spit barriers attached north of the Villa Gesell palaeo-headland continued growing and migrating, the protected environments located inland remained unaffected by the direct marine action. As a result, the energy level driving the mechanisms of formation of the southward-growing beach ridges attached to Punta Piedras diminished inducing there a change in sedimentary processes in such a way that deposition of shelly and coarser clastic sediments was progressively replaced by finer sediments. These processes of interaction between the two opposite coastal systems were responsible for the rapid evolution of the semi-enclosed very low energy environment, where tidal flats began to evolve (Fig. 6G). On the other hand, the southwestward growing barrier attached to Villa Gesell continued prograding in the same direction progressively closing the inner lagoon, and low-energy beach ridges formed at the lagoon coasts.

LAST STAGES OF THE REGRESSIVE EVENT

The coastal system of the Samborombón bay continued evolving by northward progradation of the spit barriers (which progressively shaped the San Antonio cape) and consequent infilling of the inner protected areas by fine sediment deposition. In this way, tidal flats were transformed into marshes. In the tidal coasts, storm events allowed cheniers formation, whereas in the innermost areas progressively disassociated from tidal action deflation activity began to occur.

At 1770 years BP, as a result of the setting of the delta in the de la Plata estuary (Cavallotto, 2002), a large amount of sediments began to be delivered into the bay, and as a consequence progradation of its central and southern coasts was enormously accelerated. As a result, the bay shoreline began to develop its present features and coastal configuration.

HISTORICAL TIMES

The reconstruction of the picture of historical times (Fig. 6H) is interesting since some morphological changes have been described in the last couple of centuries. During one hundred years, from the end of the XVIII till the end of the XIX centuries, natural navigation channels served ships to access the port of General Lavalle (located around 20 km west of Punta Rasa, Fig. 3), which was at that time a very important port for active commerce of leathers, salted meat and fruits with Europe. Today, shoaling and silting make impede the access the port, which is used only for local and limited fishing activities. On the other hand, earlier in time, Falkner (1774), an English naturalist and Jesuitic priest who visited the zone in the XVIII century, described a waterway cut through the barriers and dunes few kilometres south of Punta Médanos (Fig. 6H), a place where present coastal dunes show the maximum width (some 4 km). Old maps from 1875, 1884 and 1903 (mentioned

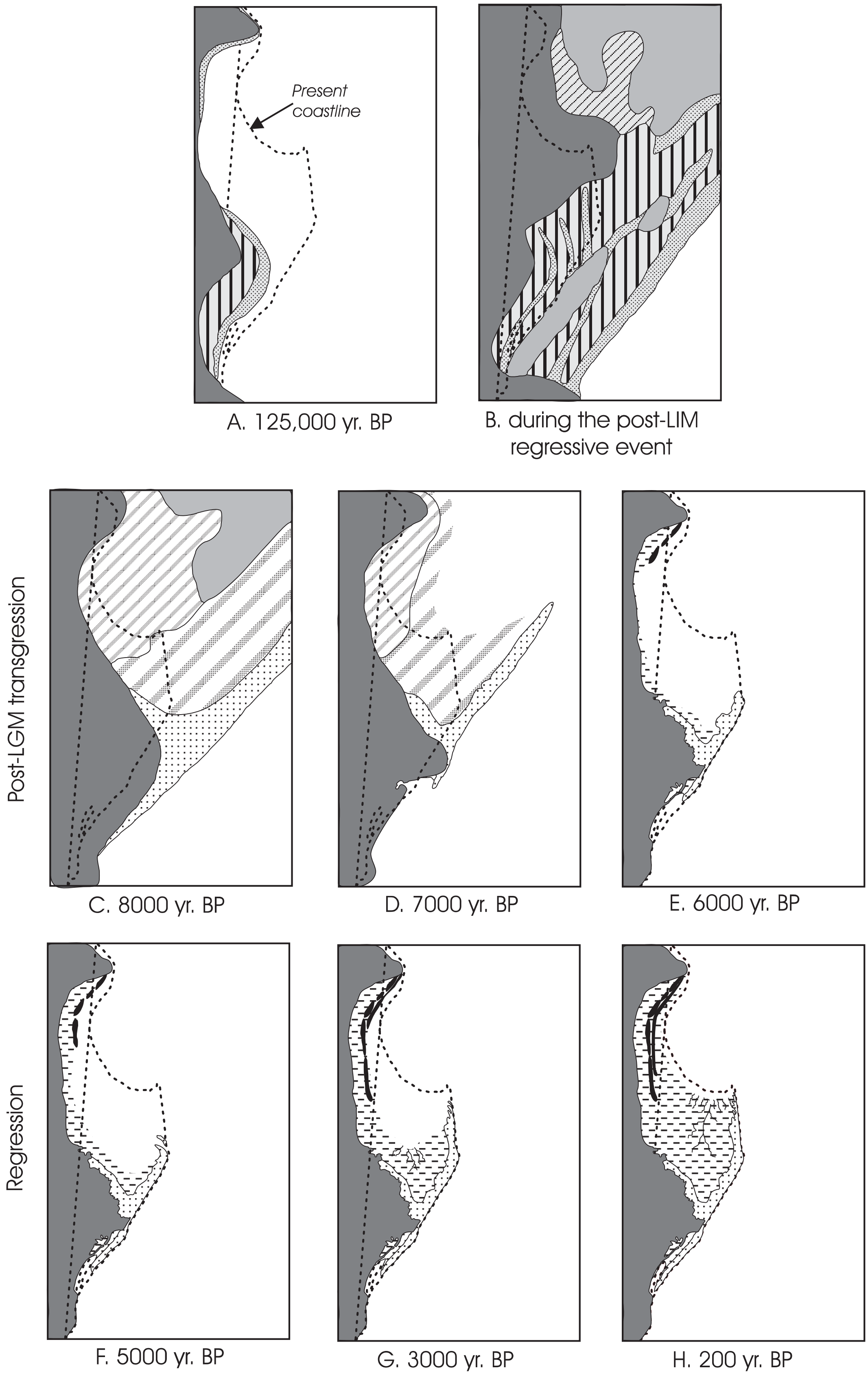

Fig. 6. Schematic evolutive stages of the area

by Dangavs, 1988) also show such openings across the dunes field. Relicts of these features are visible in aerial photographs.

PRESENT TRENDS OF EVOLUTION

Morphostratigraphical evidence indicates a long-term progradation process that induced the progressive infilling of the semi-enclosed basins during the last 6000 years of evolution. According to this evidence, a northward progradation rate of around 20 m/yr can be estimated for the coastal plain surrounding the southern part of the Samborombón bay.

However, at a shorter time-scale, some differences can be found among different regions. Punta Rasa and surroundings (Fig. 3) display opposite tendencies of evolution. Accretion processes are evident on the oceanic side of the spit through the growing of berms and the progressive invasion of sand dunes into the adjacent beach, whereas the marshes located inland experienced both erosion and deposition in different places. Shoaling, shallowing of navigation channels, infilling of tidal creeks and eolian capping at the highest parts of the marshes are also common changes in the present morphology. Bértola (personal communication) explains the simultaneous occurrence of both deposition and erosion in areas separated only a few kilometres from each other by analysing wave refraction data that indicate concentration of wave activity in some places rather than in others. The same author has measured up to 100–150 m of shoreline displacement (advance or retreating) by comparing aerial photographs and maps.

On the other hand, in the Mar Chiquita lagoon, Fasano *et al*. (1982) and Isla Mendy (1989) established the fluctuations in the position of the tidal inlet of the lagoon due to inversion processes in the net littoral drift for the last few hundreds of years through the comparison of old charts and historical data.

CONCLUSIONS

The post-glacial sedimentary sequence in the coastal plains adjacent to the Pampean region was formed by littoral dynamic processes associated to the last stages of the post--LGM eustatic event. Several facts have been relevant during the regional evolution:

1) the presence of a major relict feature (Alto Marítimo), that before 8000 years BP constituted a conspicuous subaerial feature exposed to active littoral dynamics;

2) the last stages of the sea level rise, when the Alto Marítimo was completely flooded and submerged resulting in a rapid drifting of the shoreline to the west;

3) the presence of another coastal feature (Villa Gesell headland), that after the disappearance of the Alto Marítimo became very significant in the coastal evolution as the most energetic littoral processes were concentrated there;

4) the set up of cell-type circulation systems associated to the most prominent coastal features causing the development of diverging relative higher-energy environments around the Villa Gesell headland and lower-energy environments around the Punta Piedras headland;

5) the increasing fluvial sediment supply from the de la Plata river as a result of the development of the Paraná delta.

The consequent sedimentological resultants were, first, the formation of barrier-coastal lagoon complexes extended alongshore during the transgressive event, and second, the formation of spit barriers and beach ridges during the following regressive event that evolved in opposite directions attached to the headlands. In this way two coastal plain environments formed: Samborombón and Mar Chiquita. The coastal plain surrounding the Samborombón bay resulted from a complex set of processes driven by a simultaneous development of northward migrating spit barriers attached to the Villa Gesell palaeo-headland and southward migrating beach ridges attached to Punta Piedras, as a result of which the protected areas inside underwent rapid sediment accumulation and progradation and were transformed into tidal flats and marshes. The infilling process of these areas was accelerated after the increase of sediment supply following the formation of the Paraná delta. On the other hand, the Mar Chiquita lagoon area underwent unidirectional processes of progradation as a result of the southwestward migration of a single coastal barrier. These processes are still occurring and are not going to change in the future at least while present climatic, oceanographic and/or sea level conditions remain invariable.

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