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The post-last glacial maximum transgression in the de la Plata River and adjacent inner continental shelf, Argentina

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Abstract

Deposits resulting from the last glacial maximum transgression have been studied in the lowermost regions of the del Plata fluvial basin in eastern Argentina, which include the de la Plata River and adjacent inner shelf and coastal plains. After applying the concepts of sequence stratigraphy, those deposits were considered as a unit and defined as a depositional sequence composed of two systems tracts, respectively, representing the transgressive event and the highstand of sea-level. The sequence was deposited in different but genetically linked depositional environments such as high and low energy coasts with coastal barriers, beach ridges, coastal plains, estuaries and deltas as well as inner shelf. The boundary between the sequence and the underlying pre-transgressive units is represented by the transgressive surface or unconformity (modeled by the ravinement process) which extends from the outer edge of the shelf to the coast. This surface is time-transgressive and can be recognized by distinct physical characteristics above and below it depending on the successive sedimentary environments developed in deep, shallow or coastal waters as sea-level fluctuated.

1. Introduction

The del Plata basin is a fluvial basin draining a very extensive region in northeastern Argentina as well as part of Brazil, Paraguay, Bolivia and Uruguay. The final collector is the de la Plata River, a funnel-like water body which flows into the Atlantic Ocean through a very wide mouth. As a consequence of these characteristics and the flatness of the territories surrounding the lowermost part of the basin, the Quaternary transgressions deeply affected the de la Plata River environment and adjacent areas. This work deals with the knowledge of the marine processes that occurred there during post-last glacial times.

The area comprises littoral and marine environments that constitute very interesting sites for studying marine sequences deposited during the late Pleistocene and Holocene, since the combination of coastal erosive processes and sediment deposition accompanying the post-last glacial maximum (LGM) sea-level fluctuations occurred in such a way that they affected extensive, low and very gently sloping areas. As a result, distinct sedimentary environments and facies developed during the different evolutionary stages associated with the eustatic event, which will be here referred to as "post-LGM transgression" since the expression "last glacial maximum" is simplified as LGM.

Although deposits resulting from the post-LGM transgression have been studied in the region for more than 100 years and many subaqueous geological aspects have been known since the 1960s, implementation of systematic seismic surveys in the last two decades and interpretation of the results in a sequence stratigraphy framework allowed better understanding of the complex set of geological environments and processes that characterized the regional evolution during the times that followed the LGM. These studies, focused from a "marine" viewpoint, and aimed to interpret first the subaqueous environments and then to correlate these with onshore information, constituted an innovative method in Argentina to study late Quaternary sequences and allowed a new and integral view of late Pleistocene–Holocene processes and deposits.

This paper summarizes some of the results obtained during the activities performed for the Project *Relevamiento geológico-geofísico del Margen Continental Argentino* ("Geological and geophysical reconnaissance of the Argentine Continental Margin"), supported by Argentine national offices for research (CONICET,

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SECYT) and carried out at the Argentine Navy Hydrographic Office since the late 1980s. Most of the descriptions and conclusions have already been published in Argentina (Parker and Violante, 1993; Parker et al., 1999). It is a contribution to Project IGCP 464 "Continental Shelves during the Last Glacial Cycle, Knowledge and Applications".

2. Geographical location and physiographic features

The region (34°–38°S, 54°–59°W, Fig. 1) is mainly located in eastern Argentina, adjacent to the province of Buenos Aires, although it also includes genetically associated coastal areas of southern Uruguay. The most significant feature is the de la Plata River, which is important not only for its physical configuration but also for its geomorphological significance. Its area is approximately 35,000 km^2, its maximum length is 323 km, and its width reaches a maximum of 221 km. The main tributaries are the Paraná and Uruguay rivers, carrying a water volume of 22,000 m^3/s. Sediment transport and deposition is sufficient to build a delta whose subaerial plain (Paraná Delta) is around 17,500 km^2.

The de la Plata River is located in the transition zone between the Brazilian shield and the "Pampas" region, and hence its coastal areas show different characteristics. The northeastern coast (Uruguay) (Fig. 1) is formed by low hills where the metamorphic basement of the Brazilian shield outcrops, and only in reduced strips of coast are low fluvial-estuarine Holocene environments present. The southwestern coast (Argentina) is characterized by extensive, very gently sloping and low-relief coastal plains (Fig. 2), developed over underlying Cenozoic deposits, lying below 5 m above present sea-level. These coastal plains were significantly affected by Quaternary glacial-eustatic sea-level fluctuations and particularly by the post-LGM transgression.

Despite its very large size, the de la Plata River has a very shallow and smooth bottom no deeper than 10 m over most of its course with a medium depth of 6 m, except near the river mouth where depths greater than 20 m can be reached. The river bed (Fig. 2) constitutes a deltaic platform (Parker and Marcolini, 1992) where the main reliefs are shoals and channels associated with recent fluvial and tidal dynamics (Cavallotto, 1988). Instead, the outer section of the river is particularly characterized by the presence of relict pre-Holocene features such as the Alto Marítimo (Cavallotto, 1988; Parker et al., 1999). The lowest part of the main tributaries of the de la Plata River (Paraná and Uruguay rivers) is separated from each other by a set of Holocene features that comprise the Paraná delta and the Entre Ríos coastal plains (Fig. 2).

South of the river mouth extends the inner shelf, which is a very gentle surface with a slope less than 0.06% whose outer limit reaches around 70 m depth. At

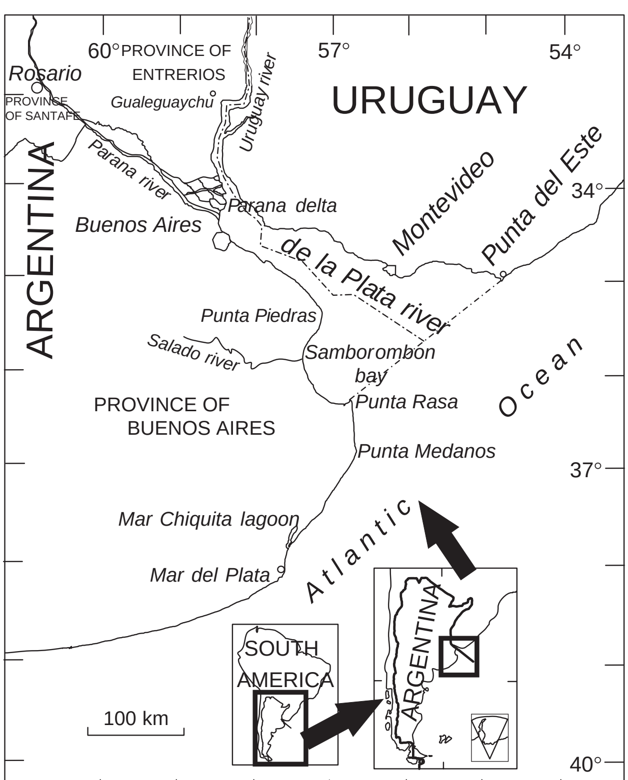

Fig. 1. Location map.

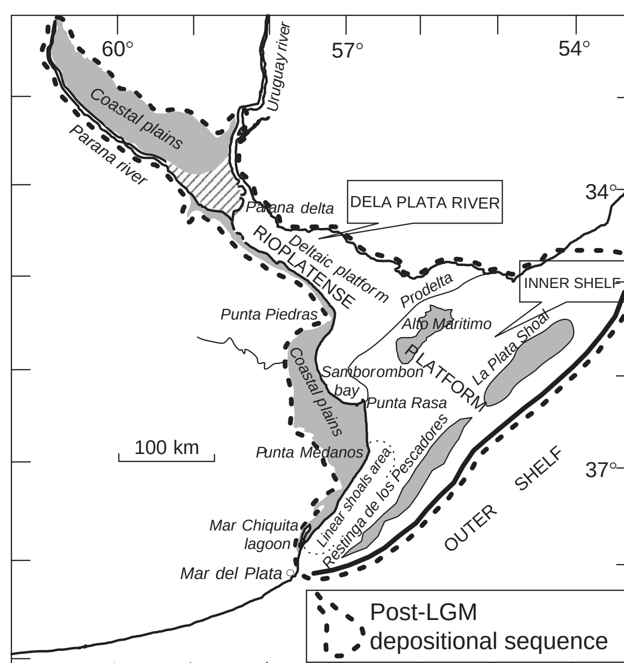

Fig. 2. Regional distribution of the post-LGM depositional sequence and its main morphological features.

the inner shelf outer edge, two main features are present (Fig. 2): La Plata shoal (an early transgressive feature related to former stages of the post-LGM transgression probably older than 10,000 yr BP); and Restinga de los Pescadores (a pre-Holocene relict feature) (Parker et al., 1999). Shorewards, in the area between Punta Rasa and Mar del Plata (Fig. 2), the inner shelf reaches 7–10 m depth at the foot of the shoreface. On the shelf surface sediments are arranged in different morphological features. In the northernmost areas shoals and channels dominate, whereas in the southern areas located between Punta Médanos and Mar Chiquita lagoon linear shoals attached to the coast are present (Parker et al., 1978, 1982; Swift et al., 1978) (Fig. 2).

The coastline along the Argentine side of the de la Plata River and inner shelf is delineated by three rectilinear sections (Fig. 2): north section, located north of Punta Piedras, where the coast has a northwest–southeast orientation; central section, between Punta Rasa and Punta Médanos, where it has a north–south orientation; and south section, south of Punta Médanos, where the orientation of the coastline is north-north-east–south-southwest. The mentioned coastal locations (Punta Piedras, Punta Rasa and Punta Médanos) represent key points for coastal dynamics acting during ancient and present times (Violante and Parker, 1992; Parker et al., 1999; Violante et al., 2001). Between the north and central sections is the most noticeable coastal feature, Samborombón Bay, a very large coastal inflection 100 km wide at its mouth and extending inland 40 km to the innermost part (Fig. 2). Coastal plains are low, gentle sloping areas with a slope less than 0.1% and no higher than 5 m above present sea-level, with the exception of few features exceeding that height as beach ridges reaching 6 or 7 m in the area adjacent to the de la Plata River and coastal dunes up to 30 m high at the oceanic coast.

The deltaic platform, inner shelf and adjacent coastal plains constitute a major landform, the Rioplatense Platform (Parker et al., 1999) (Fig. 2). Part of this feature, located in the inner shelf, is the Rioplatense Terrace, which includes the subhorizontal surface as well as the upper and lower steps that limitate its inner and outer edges. This terrace represents the abrasion surface formed by the post-glacial transgression that has not been covered by the regressive coastal wedge that includes the coastal plains and the deltaic platform.

3. Geological setting

The region is included in the Argentine Continental Margin, which is a passive margin structurally characterized by stable continental blocks with neither seismic activity nor tectonic deformation at least since Mesozoic times. Perpendicular to the margin and to the Brazilian Shield is the Salado Basin (Fig. 3), which is genetically linked to the rift-valley between South America and Africa formed as a consequence of the first ocean opening in Jurasic–Cretaceous times. It is stratigraphically represented (Bracaccini, 1980; Tavella and Wright, 1996) by Precambrian–Paleozoic metamorphic and upper Jurasic–lower Cretaceous volcanic rocks that underlie a middle Cretaceous–Tertiary–Quaternary sedimentary cover up to 6000 m thick, with deposits from continental to marine environments in the continent changing to exclusively marine under the shelf. The upper levels of this sedimentary sequence are younger than Miocene, and can be divided into three major units. The lower one is composed of Miocene green clays with marine fosils; the intermediate one is represented by Pliocene fluvial sands on the continent that change to equivalent coastal to marine facies towards the shelf; and the upper one is formed by upper Pliocene to Pleistocene loess-like deposits on the continent that change seawards to marine in an arrangement representing at least four different transgressive events (Parker et al., 1999; Violante and Parker, 1999). The Salado basin was under tectonic subsidence during most of its history, but since the Tertiary it gradually decreased in such a way that during the Quaternary the glacial-eustatic sea-level fluctuations were able to impress their own characteristics. The present de la Plata River represents the final stage of an

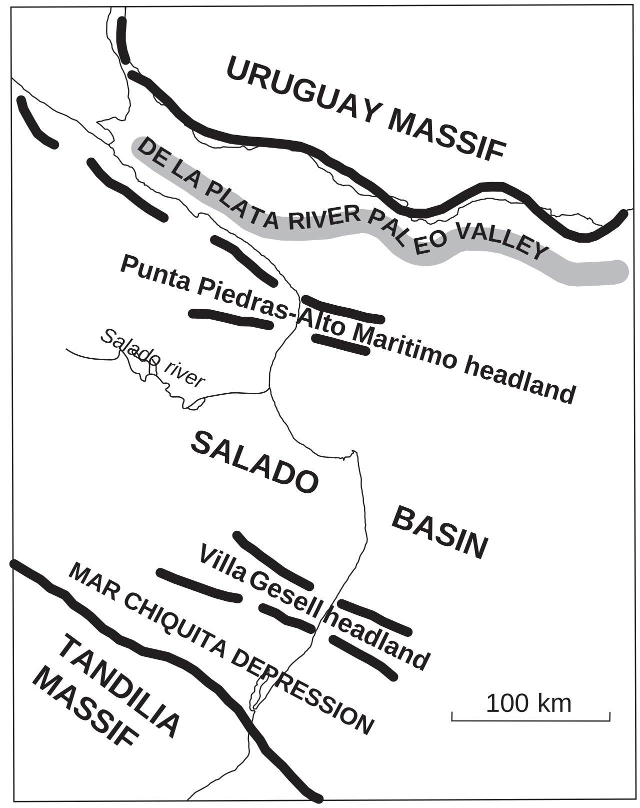

Fig. 3. Main regional morphostructural features of the area.

evolutionary history that begun around 2.4 Myr ago when a fluvial environment was installed (Parker et al., 1994), followed by successive transgressions and regressions which occurred during the Plio-Pleistocene that affected the region before the onset of the post-LGM transgression (Violante and Parker, 1999).

4. Methods of study

Underwater geological and geophysical surveys designed to study the uppermost sedimentary sequences in shallow waters with different techniques such as high-resolution and low-penetration seismic, side-scan sonar, echosounding, grab and piston core sampling as well as submarine photography were undertaken in five cruises programmed during the Project execution. We obtained 5000 km of seismic lines, 45 piston cores and around 250 grab samples. Compiling of geological data from former cruises and from the references obtained additional information in such a way that a total of 1200 grab samples and 112 piston cores were finally used. At the same time, compiling of different bathymetric surveys performed in the last 70 yr allowed construction of the general bathymetric map for the area at scale 1:250,000 and 1 m contourline spacing. On the other hand, terrestrial geological campaigns undertaken in the adjacent coastal plains, which included the drilling of 46 boreholes up to 30 m long, and the use of data available from around other 60 boreholes, provided knowledge of the coastal stratigraphic sequence that was later compared and correlated with the submarine geological information.

5. Characteristics of the post-LGM deposits

The de la Plata River, shelf areas of northeastern Buenos Aires province and adjacent coastal plains have been affected by the last transgressive event as a whole. As a consequence, the resulting sedimentary sequence constitutes a unit (Fig. 2) although it shows distinct characteristics according to local features and processes in each of those environments. These characteristics are here briefly described, preceded by a short review of former works whose compilation, added to new geological–geophysical studies, established regional geological knowledge.

5.1. de la Plata River

The first geological aspects of the river subsurface were mentioned as early as the end of the 19th and the beginning of the 20th centuries (Ameghino, 1880; Roveretto, 1911). Since then, no other studies dealt with the area until the works by Urien (1966, 1967), who made the first detailed descriptions on the estuarine–fluvial–deltaic sedimentary environments. Parker (1990) built the first Holocene stratigraphic sequence, and Parker et al. (1986, 1999), Cavallotto (1988), Parker and Marcolini (1992), and Parker and Violante (1993) described most of the geological, seismic, sedimentological and evolutionary characteristics of the late Pleistocene and Holocene deposits.

The post-LGM sequence is constituted by two depocenters. The lower one corresponds to an estuarine environment composed of muddy sediments, whereas the upper one represents a prograding delta complex composed of sands, silts and clays distributed in a downstream fining sedimentary sequence.

5.2. Shelf

The post-LGM sedimentary sequence was identified by seismic methods and defined first as a seismic-stratigraphic unit (Parker et al., 1990a, b) and then as a depositional sequence (Violante et al., 1992; Parker et al., 1999). Previous studies by Urien (1967, 1970), Urien and Mouzo (1968), Urien and Ewing (1974), Urien et al. (1978), Parker and Violante (1982), Marcolini et al. (1992) and Parker et al. (1996) described most of their environmental and sedimentary characteristics.

The unit constitutes an almost continuous sandy sheet relatively uniform in thickness which lacks in few places where pre-transgressive sediments outcrop as in the Alto Marítimo, Restinga de los Pescadores, outer step of the Rioplatense Terrace and depressions between linear shoals. Those sandy sediments are relict of transgressive littoral barriers systems that migrated across the shelf during the last sea-level rise.

5.3. Coastal plains

Characteristics of Holocene deposits in the coastal plains surrounding the de la Plata River and adjacent shelf were known since 1842, when D'Orbigny (in Consejo Federal de Inversiones, 1975) first differentiated the shell ridges located there. During the last years of the 19th century, many other writers (compiled by Cortelezzi and Lerman, 1971; Dangavs, 1988) increased the regional geological knowledge. With Doering (1882) and Ameghino (1880, 1889, 1908) the first stratigraphic organization of coastal Holocene deposits in the area and the rest of the coasts of Buenos Aires province was made. Frenguelli (1950, 1957) established, on the basis of Ameghino's works, the regional stratigraphic schemes that are still in use. From that moment on, more detailed studies concentrated in relatively small specific working areas were carried out (with the only exception being the regional work by Tricart, 1973), in such a way that a progressive detailed covering of the entire coastal plains was obtained (Groeber, 1961; Cigliano, 1966;

Cortelezzi and Lerman, 1971; Fidalgo et al., 1973a, b, 1975; Cortelezzi, 1977; Fidalgo, 1979; Parker, 1979, 1980; Schnack and Gardenal, 1979; Iriondo, 1980a, b; Schnack et al., 1980; Fidalgo et al., 1981; Fasano et al., 1982; Fidalgo and Tonni, 1982; Schnack et al., 1982; Dangavs, 1983; Fidalgo and Martínez, 1983; Iriondo, 1983; Guida and González, 1984; Ravizza, 1984; Gómez et al., 1985; González and Ravizza, 1987; Spalletti et al., 1987; Dangavs, 1988; González et al., 1988; Violante, 1988; Weiler and González, 1988; Codignotto et al., 1992, 1993; Cortelezzi et al., 1992; Violante, 1992; Violante and Parker, 1992; Codignotto and Aguirre, 1993; Aguirre and Whatley, 1995; Cavallotto et al., 1995a, b, 1999; Colado et al., 1995; Cavallotto, 1996; Bértola et al., 1998; Violante et al., 2001; Cavallotto et al., 2002). Zárate (1989), although working on Pleistocene sediments, first introduced the use of allostratigraphic units for the Argentine Quaternary, later applied to Holocene coastal deposits by Parker and Violante (1993) and Violante and Parker (2000).

The Holocene sedimentary sequence in the area constitutes a clastic coastal wedge, which has different characteristics depending on its association to the de la Plata River or to shelf areas. In the fluvial coasts it is formed by littoral sandy to shelly ridges connected to estuarine evolution. In the marine coasts the sequence is represented in the base by a fining upwards transgressive hemicycle composed of sandy barriers sediments similar to the shelf sands, interbedded with muddy coastal lagoons facies, whereas the upper section contains sandy and muddy beach, tidal and eolian deposits which constitute a fining upwards prograding hemicycle. Coasts around Samborombón Bay represent a transition zone between fluvial and oceanic coasts where muddy tidal flats extend along most of the area.

6. Factors conditioning regional evolution during post-LGM times

6.1. Post-LGM sea-level fluctuations

The region was affected by the transgressive event that occurred as a consequence of deglaciation after the LGM (Fig. 4). The oldest age related to this event registered in the Argentine shelf is 18,700 ± 500 yr BP (Fray and Ewing, 1963), which is an uncorrected ^{14}C age obtained from shells contained in a piston core located 1600 km south of the studied area at a water depth of 157 m. In the vicinity of the studied area, however, ages coming from cores at water depths ranging from 10 to 120 m are not older than 15,000 yr BP uncorrected ^{14}C (Fray and Ewing, 1963; Parker and Violante, 1982). Guilderson et al. (2000) resampled the same cores that Fray and Ewing used (recovered by Lamont–Doherty Geological Observatory in the late 1950s and early

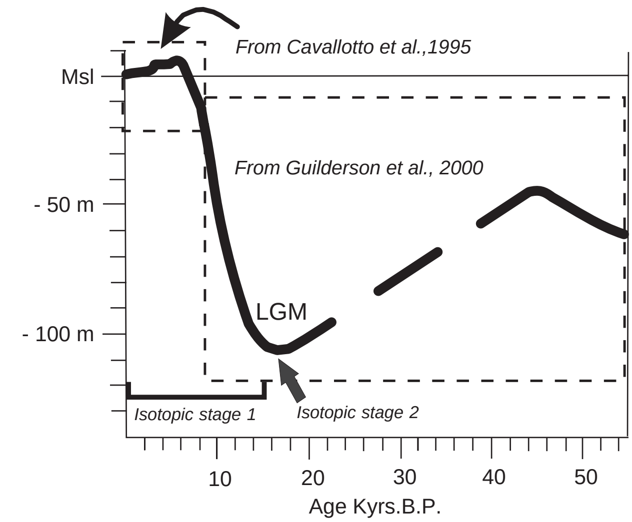

Fig. 4. Relative sea-level curve, compiled after Cavallotto et al. (1995b) and Guilderson et al. (2000).

1960s), in order to reconstruct a eustatic relative sea-level curve for the Argentine shelf by dating shells with AMS ^{14}C. The curve so obtained shows a minimum sea-level around 16,690 yr ago at 157 m below present level. After subtracting isostatic and tectonic effects, Guilderson et al. (2000) concluded that the eustatic component of sea-level rise during the following transgression was 105 m (Fig. 4), although these results cannot be definitely confirmed and definition of the LGM is still not clear with the current data.

With the onset of deglaciation, corresponding to OIS 2, sea-level began to rise rapidly, accompanied by coastal retreat (Fig. 4). No conclusive evidence has been found yet showing significant interruptions in the rate of sea-level rise prior to 8600 yr BP. However, the erosional features characterizing the outer step of the Rioplatense Terrace which expose the Plio-Pleistocene marine sequences and interrupt the distribution of the last transgressive deposits (Fig. 5), could indicate the action of more intense erosive processes associated either to an interruption in the rising of sea-level or to a moment of some vertical land movements (Violante et al., 1993). The first possibility is presently considered as the most probable situation. After 8600 yr BP sea-level fluctuations are well documented for the area (Cavallotto et al., 1995b, this volume; Violante and Parker, 2000). These authors considered that between 8600 and 6000 yr BP sea-level rise slowed until it reached around +6 m above present (relative position, see Cavallotto et al., this volume), followed by a progressive sea-level fall occurring at different rates before reaching its present position. The mentioned characteristics of sea-level fluctuations for the last part of the Holocene agree with the statement of Isla (1989) concerning the occurrence of higher than present sea-levels during the Holocene as the common situation for the Southern Hemisphere.

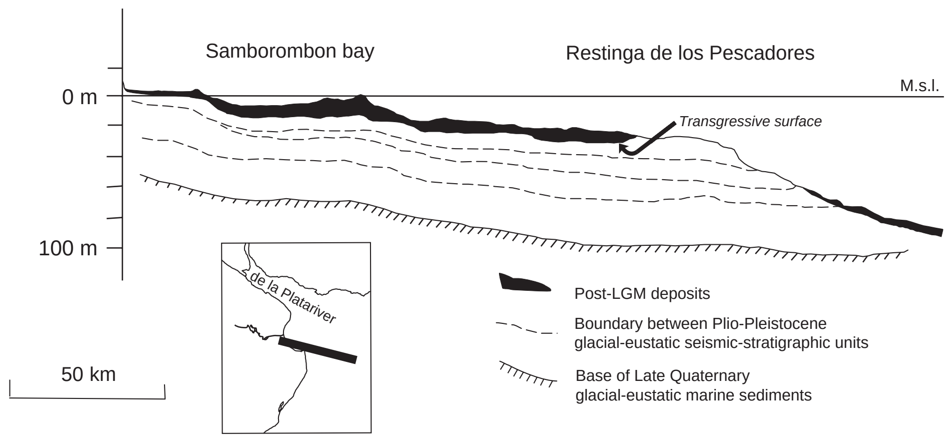

Fig. 5. Position of the post-LGM depositional sequence in the coastal and marine areas in relation to underlying Plio-Pleistocene glacial-eustatic sequences (after Parker and Violante, 1993).

6.2. Sediment supply

Sedimentation in the region during the post-LGM transgression was controlled by three sediment sources.

6.2.1. Fluvial discharge from de la Plata fluvial basin

Sediments from cratonic areas of Brazil and central Argentina, the Andes and the forests in eastern Bolivia, Paraguay and western Brazil were transported by rivers flowing into the de la Plata River and deposited both in the estuarine–deltaic body and in the adjacent coastal plains in a fining downstream sequence (Parker et al., 1987; Parker and Marcolini, 1989). As a result, coarse and medium sandy sediments dominate in fluvial valleys, fine sands and silts constitute most of the subaerial and subaqueous delta as well as the coastal plains, and clays form both the present prodelta facies and the ancient estuarine environment that constitute the bed of the present de la Plata River.

6.2.2. Northwards littoral transport from Pampean and Patagonian coasts

These processes occurred uninterrupted during the Quaternary glacial-eustatic transgressive-regressive cycles and transported the products of erosion of volcanic–pyroclastic sequences that constitute the coastal cliffs. The different coastal systems that form most of the shelf surface are dominated by these sandy deposits.

6.2.3. Erosive processes acting on successive coastal environments during the coastal retreat resulting from the last transgressive event

These processes gave origin to the ravinement surface which was later flooded by the sea and covered by relict and palimpsestic transgressive sediments (Swift et al., 1978; Parker and Violante, 1982).

6.3. Coastal dynamics

Coastal dynamics regulating sediment transport and deposition varied in the different sedimentary environments. Parker et al. (1999) and Cavallotto et al. (this volume) summarize the present fluvial and oceanographic conditions of the region, but there is still not much information concerning conditions during former sea-level stages. As a general rule, in the de la Plata River dominant processes are, in decreasing importance, the hydraulic gradient, tides, and littoral currents. Hydraulic gradient produces the fining downstream grain size sequence in the river bed. Tides become more important in the middle and outer parts of the river where their action is responsible for the formation of tidal banks (Cavallotto, 1988). Littoral currents driven by waves coming from the south redistribute fluvial sediments on the coasts. In the river mouth where fluvial and oceanic waters meet (maximum salinity gradient zone) clay flocculation is a distinctive process that produces a maximum turbidity zone or muddy depocenter (Cavallotto, 1996). During former stages of the transgression, all these processes moved upstream and downstream accompanying the rising and falling of sea-level.

On the other hand, in shelf areas the dominating process is the action of littoral currents, which were in the past responsible for sediment distribution along the successive oceanic coasts that migrated inland as sea-level rose. Although some local cell circulation acted around prominent coastal accidents as Punta Piedras-Alto Marítimo and Villa Gesell headlands (Fig. 3) which behaved as diverging points for littoral drift with the consequent formation of individual littoral systems (Violante and Parker, 1992; Parker et al., 1999; Violante et al., 2001), regional sediment transport during the Holocene was to the north.

6.4. Substratum characteristics

The surface underlying the post-LGM sedimentary sequence (Fig. 6) is the result of: (1) the topography and lithology of pre-transgressive relict relief; (2) the modification of the relict surface during its exposure to subaerial conditions before the onset of the last transgression; (3) the rate of relative sea-level rise; (4) the ravinement effect during the transgression; (5) the sediment supply; and (6) the balance between erosion and deposition at each stage of the transgression.

As a result of interaction among all these factors, distinctive morphogenetic features can be recognized from north to south (Fig. 3): the Uruguay massif, the de la Plata River paleovalley, the Punta Piedras-Alto Marítimo headland, the Samborombón depression, the Villa Gesell paleo-headland, the Mar Chiquita depression, and the Tandilia massif. The cratonic regions of Uruguay and Tandilia limited the area of marine flooding during the last transgressive event, whereas the Punta Piedras-Alto Marítimo and Villa Gesell headlands represent relict Pleistocene features that separated different Holocene environments (Parker et al., 1999; Violante et al., 2001). Main areas of deposition of transgressive deposits are the central part of the Salado basin where open-to-the-sea barrier systems developed, the de la Plata River paleovalley where estuarine deposition dominated, and the Mar Chiquita basin where coastal lagoons were formed. During the last stages of the transgression the sea flooded the easternmost part of the Pleistocene headlands in such a way that the three areas of Holocene deposition coalesced and gave origin to the present geomorphological environments.

6.5. Tectonics

Tectonics seem to have not been very important in regulating sediment distribution during post-LGM times in the de la Plata River area, although it is a factor that cannot be denied. The general idea is that uplifting occurred at least during the Holocene after a progressively decreasing subsidence at the end of the Pleistocene, but the rate of these movements has not been definitively measured yet although some evidence was already mentioned (Parker, 1979; Codignotto et al., 1992; Parker and Violante, 1993; Violante et al., 1993; Guilderson et al., 2000). Parker et al. (1999) and Cavallotto et al. (this volume) give a description and discussion of all the possible tectonic variables.

7. Sequence stratigraphy

The regional post-LGM stratigraphic sequence was established after comparing and correlating both

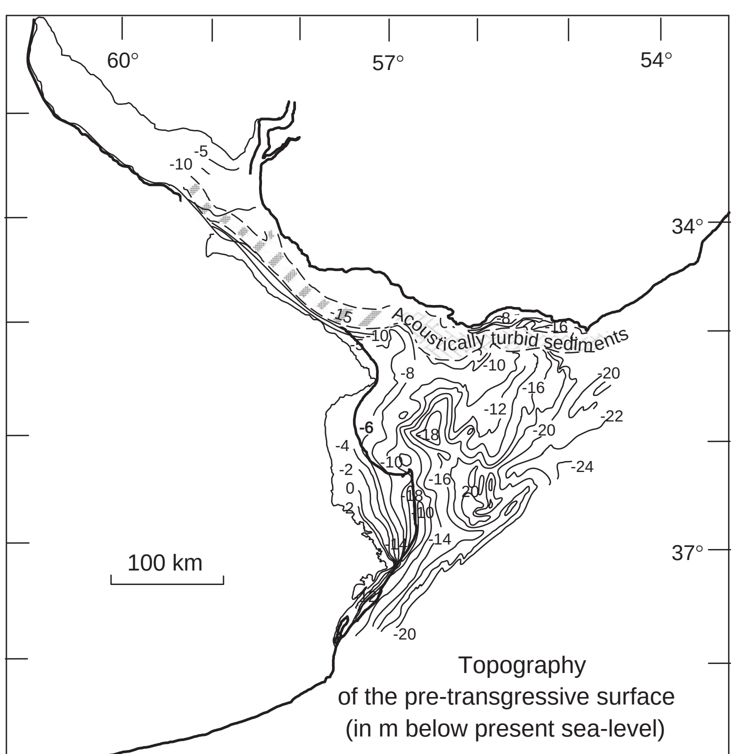

Fig. 6. Topography of the pre-transgressive surface. Numbers are given in meters below present sea-level. Line spacing is 2 m (modified from Parker et al., 1999).

underwater and terrestrial information obtained through different methods of study. On the continent, information from outcrops and boreholes allowed recognition and correlation of lithofacies. They were defined, following the concepts by Reading (1986) and Walker (1992), as depositional paleoenvironments characterized by uniform sedimentation conditions. This "paleoenvironmental" viewpoint allowed use of the concept of alloformations instead of lithosomes, as alloformations, as defined by the North American Commission on Stratigraphic Nomenclature (1984), are closely related to paleogeographical and paleoenvironmental conditions (Parker and Violante, 1993; Violante and Parker, 2000). By applying the concepts of seismic stratigraphy (Brown and Fisher, 1977; Mitchum et al., 1977; Posamentier et al., 1988) it is concluded that genetically linked depositional paleoenvironments or alloformations constitute a depositional system. The lateral succession of contemporary depositional systems forms a system tract that represents the evolutionary stage at a particular level of the eustatic curve (transgressive, highstand or regressive). Vertical successions of these system tracts which comprise a full cycle of sea-level fluctuation constitute the depositional sequence, limited above and below by regional unconformities.

At sea, use of indirect surveying methods as high-resolution seismic allowed identification of packages of concordant reflections (seismic-stratigraphic units), separated by seismic discontinuity surfaces that represent regional unconformities. Internal variations of seismic-stratigraphic units are recognized as seismic facies.

This method of study allows correlation of unconformities recognized in the marine and terrestrial areas as well as the corresponding sets of sedimentary environments located above and below them. In this way, depositional sequences are equivalent to seismic-stratigraphic units, and hence they are composed of systems tracts which include different depositional systems or alloformations. As a result of the application of these concepts in the studied area, it was possible to obtain a complete picture of the post-LGM transgressive deposits.

8. The post-LGM depositional sequence in the de la Plata River and surroundings

The sequence represents an almost continuous sedimentary unit extending from the lowest sections of the Paraná and Uruguay rivers to the inner shelf, including the de la Plata River and adjacent coastal areas (Figs. 2 and 7), and probably extends even towards the continental slope. Its base is represented by the unconformity that separates it from underlying Plio-Pleistocene units, whereas its top is the present topographical surface still in evolution (Violante et al., 1992; Parker and Violante, 1993; Parker et al., 1999). An internal unconformity separates the transgressive and regressive hemicycles or systems tracts composed of depositional systems or alloformations. A lowstand system tract has not been yet found in the outer shelf and continental slope areas, but in the outer shelf in front of Río Grande do Sul, southern Brazil, relicts of the former deltas related to the ancient de la Plata River mouth located there during LGM times have been described by Urien et al. (1978). The following short descriptions are based on more detailed works by Violante et al. (1992), Parker and Violante (1993), Parker et al. (1999) and Violante and Parker (2000).

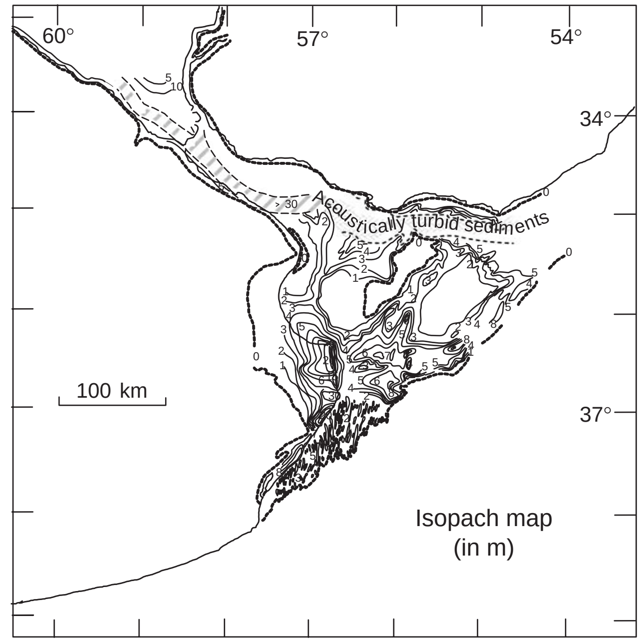

Fig. 7. Isopach map of the post-LGM depositional sequence (numbers given in meters) (modified from Parker et al., 1999).

8.1. Transgressive system tract

This corresponds to the sedimentary mantle deposited during the last sea-level rise (between 18,000 and 6000 yr BP, Fig. 8). It is composed of three depositional systems: relict transgressive, littoral barriers–lagoons and estuarine.

8.1.1. Relict transgressive depositional system

A mantle of medium to fine sands covers most of the middle and inner shelf. These sediments were deposited in successive littoral barrier environments that migrated across the shelf during the transgression, but after deposition they were reworked by the ravinement effect and remained on the shelf surface as relicts of former shorelines (Urien, 1967; Parker et al., 1978, 1982; Parker and Violante, 1993).

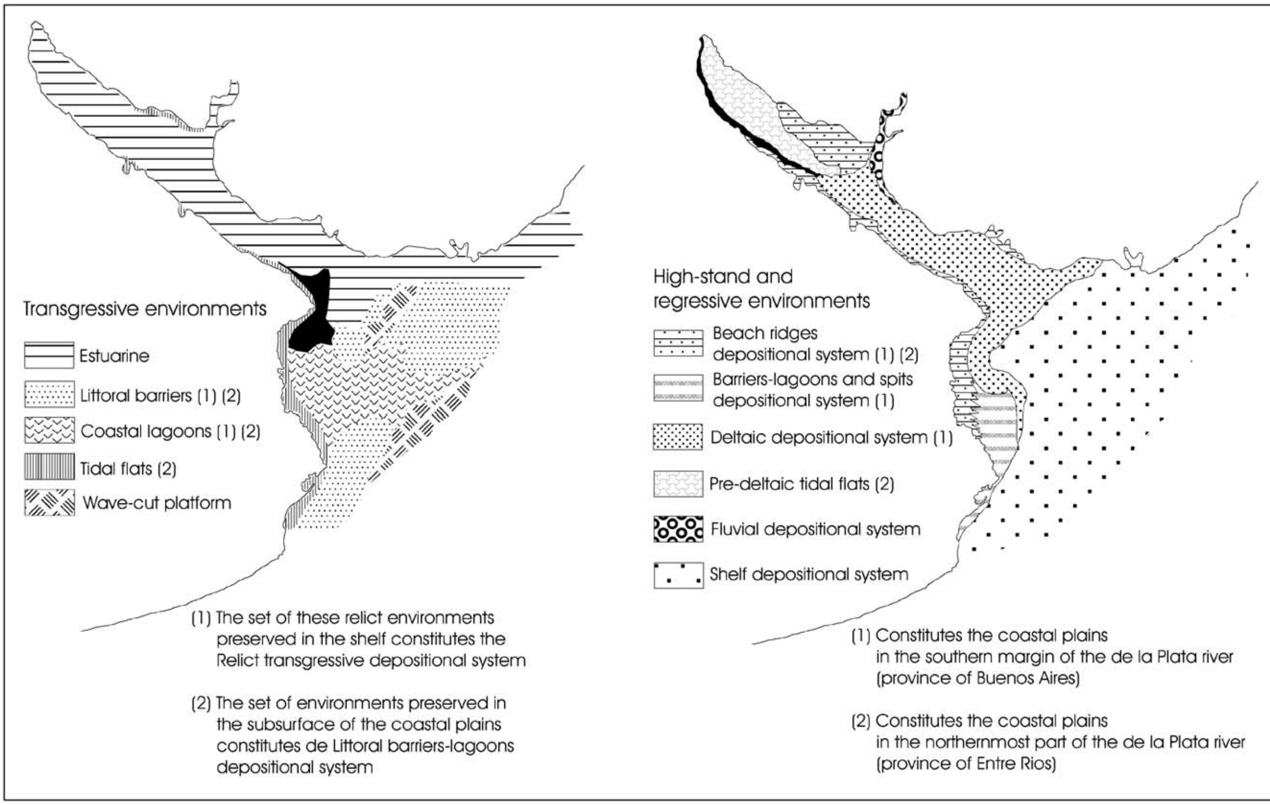

Fig. 8. Post-LGM systems tracts, depositional systems and environments. Left: transgressive; Right: highstand. Compare with Fig. 1 for geographical indications and sites location (modified from Parker and Violante, 1993).

8.1.2. Littoral barriers–lagoons depositional system

The uppermost transgressive littoral barriers system was formed in open oceanic coasts when sea-level reached its highest position. As at that moment transgressive ravinement processes stopped, barriers and associated coastal lagoons remained preserved and are today found in the subsurface of the coastal plains (Parker et al., 1978). They are constituted by a coarsening upwards sedimentary sequence resulting from transgressive superposition of sandy barrier beaches facies over muddy lagoon facies.

8.1.3. Estuarine depositional system

In the de la Plata River, deposition during the transgressive event was mainly estuarine. Sediments are greenish gray clays with shells and organic matter and cover most of the river paleovalley that extended from the outer shelf in southern Brazil to the lower Paraná River in eastern Argentina near the city of Rosario (Groeber, 1961; Urien, 1970; Parker and Violante, 1993; Cavallotto et al., 2002) (Figs. 1 and 8).

8.2. Highstand system tract

This is constituted by the prograding deposits that resulted from sedimentation during the sea-level fall between 6000 yr BP and the present (Fig. 8), and hence is still in evolution. It is formed by six depositional systems: shelf, barriers–lagoon and spits in marine coasts, beach ridges in estuarine coasts, deltaic, pre-deltaic tidal flats, and fluvial.

8.2.1. Shelf depositional system

During the regressive event, clastic sedimentation in the shelf was not significant. Instead, reworking of the upper levels of the transgressive sands was the dominant process. As a result, the bed morphology was adjusted to the present dynamic conditions and relict sediments became palimpsests. The evidence for these processes is the linear shoals systems developed in the southern part of the studied area (Parker et al., 1978, 1982; Swift et al., 1978).

8.2.2. Barriers–lagoons and spits depositional system

Coastal areas adjacent to the seashore evolved during this stage of sea-level by progradation of barriers and spits systems attached to prominent coastal features such as Villa Gesell headland (Violante and Parker, 1992). Littoral sediment drift induced by wave action around that point produced cell-type circulation, the most important process producing reorientation of the coastline, which was progressively attaining its present configuration. Coastal lagoons and tidal flats characterize the protected areas behind the barriers and spits.

8.2.3. Beach ridges depositional system

Littoral areas vinculated to the de la Plata River (including Samborombón Bay and southern Entre Ríos province, Fig. 8) were characterized by low energy prograding coasts with shelly and sandy beach ridges and cheniers as well as muddy tidal flats. These environments also evolved in response to a cell-type circulation around prominent coastal features as Punta Piedras (Cavallotto, 1996; Violante et al., 2001) and Gualeguaychú (Cavallotto et al., 2002) (Figs. 1 and 8).

8.2.4. Deltaic depositional system

Fluvial sediment transport by the Paraná and Uruguay rivers forms a delta that constitutes the de la Plata River bed. Subaerial facies extend to the river head, and subaqueous facies occupy the remainder of the river bottom down to its mouth where prodelta facies developed. Sediments are arranged in a fining downstream sequence, changing from sands and coarse silts in the upper delta to clays in the prodelta (Parker et al., 1987; Parker and Marcolini, 1992). The delta begun to form over estuarine sediments around 1770 yr ago after a significant increasing in fluvial discharge during the sea-level retreat due to changing climatic conditions (Cavallotto et al., 2002, this volume).

8.2.5. Pre-deltaic tidal flats depositional system

The first stages of the regressive event were characterized by the development of tidal flats in the uppermost estuarine areas (Iriondo, 1983; Cavallotto et al., 1999). Evolution of these environments was interrupted when fluvial activity became more important and the delta begun to form (Cavallotto et al., this volume).

8.2.6. Fluvial depositional system

In fluvial environments that have never been covered by the sea, such as the middle and upper Paraná and Uruguay rivers as well as other rivers of the Pampean region, fluvial deposition was the exclusive process during the time elapsed since the LGM to the present. Similar facies extend under the present submerged river valleys and represent the fluvial environments during lower than today sea-level positions.

9. Evolutionary history and the significance of the transgressive surface

The post-LGM depositional sequence in the de la Plata River and adjacent marine and coastal regions was deposited in the context of a significant climate change represented by the end of the glacial epoch, manifested through a rising of sea-level. There is no evidence at present about the occurrence of the consequent isostatic rebound of the continental margin. The former records of the transgressive event are represented by littoral facies associated to ancient shorelines located at the shelf edge near the lowermost positions reached by the sea around 18,000 yr ago, at the time of the LGM. From that moment on, shorelines and associated littoral environments migrated landwards across the shelf accompanying the sea-level relative rise. Coastal erosion at the retreating shoreline gave origin to a ravinement surface. As a consequence of this process, relicts of littoral facies were progressively covered by transgressive deposits (Fig. 8) which were mainly sandy on the shelf and muddy in the estuarine environment of the de la Plata River. In this way the transgressive unconformity developed. A probable interruption in the sea-level rise is suggested by the stepping at the edge of the Rioplatense Terrace (Fig. 5), but conclusive evidence does not exist yet and the situation must be studied in detail before establishing a definitive conclusion.

At 6000 yr BP sea-level reached its highest position. The following sea-level retreat that occurred from 6000 yr BP to the present was accompanied by coastal progradation which resulted in the formation of large coastal plains associated with both the de la Plata River and the sea coasts, as well as the estuarine retreating with the consequent delta formation in the de la Plata River and significant sediment reworking in inner shelf areas (Fig. 8).

It is evident that the sequence constitutes a unit deposited during the last 18,000 yr of evolution of the area (Fig. 5). Although some fluctuations in sea-level rise may have occurred during the transgression, as suggested above, the most significant interruption into the sequence is represented by the change from transgressive to regressive deposits at 6000 yr BP. These events, together with local paleoenvironmental characteristics, have originated different sedimentary arrangements. Recognizing of these arrangements and associated sedimentary characteristics above and below the transgressive surface are important aspects to take into account for a better understanding of processes related to the post-LGM events in the studied region.

A key process associated with sea-level fluctuations was the change in base level. As the sea begun to rise with the onset of the transgression, the consequent decreasing in base-level induced sediment trapping at the ancient river mouths which were thus transformed into estuaries whose relicts are today submerged under the shelf surface. As sea-level rise proceeded, high-energy coastal environments such as barrier beaches moved landwards above the previous estuaries and rivers. At the same time, in the stretch of coasts between river mouths, wave activity was dominant and erosive processes took place so progressively affecting the coastal environments, in such a way that a resulting ravinement surface advanced landwards, thus producing coastal retreat. The shelf floor was in this way covered by relict coastal sediments left behind by the complex set of erosive and depositional processes (Fig. 9). In full-marine environments like these, the unconformity represented by the transgressive surface can be recognized by the presence of littoral deposits lying above pre-transgressive sequences either littoral or fluvial.

On the other hand, a different picture resulted in interfluvials. There, soil formation continued during the first stages of the transgressive event until pedogenetic processes were interrupted when sea-level flooded these places. The transgressive surface is in consequence marked by the presence of paleosols underlying littoral sediments (Fig. 9).

While in transgressed areas the mentioned events occurred, in those areas that have never been flooded by the sea, although they were affected by the rise in base-level, two main processes took place. River valleys became progressively filled with sediments due to the loss in capacity of fluvial sediment transport, whereas in interfluvials soil formation continued uninterrupted up to the present day and no evidence of unconformities exists there (Fig. 9).

As a result, the record of post-LGM transgressive deposits varies between two extreme positions (Fig. 9). At the shelf edge, the sequence is represented by littoral and marine sediments that comprise the complete time span from the beginning of the transgression up to the present. Instead, on the continent, only the uppermost littoral sediments deposited during the last stages of the transgression are present lying above fluvial deposits or paleosols. Intermediate positions between them are composed of incomplete marine sequences deposited from the moment when sea-level began to affect the locations, but previous stages of the transgression are lacking because interrupted fluvial or edaphic sequences are present there which represent the time elapsed since the glacial epoch when the area was exposed to subaerial action to post-glacial times shortly before submergence (Fig. 9).

Consequently, the transgressive surface is time-transgressive with its older age at the shelf border (around 18,000 yr BP) and the younger at the coastal areas (around 6000 yr BP), and it separates different sedimentary facies depending on the place of observation (Fig. 10). As pre-transgressive sediments are shorewards onlapped by progressively younger deposits, the unconformity represents a hiatus that is shorter-in-time in the deepest areas and larger-in-time on the coast (Fig. 10).

Physical evidence of sediments lying below and above the transgressive surface can be easily recognized in shelf areas through their seismic character as reflected in high-resolution and low-penetration seismic records, as well

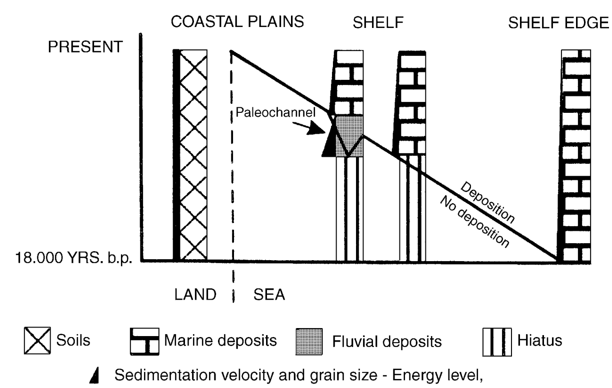

Fig. 10. Chronology of the transgressive deposits and its physical characteristics depending on the geographical location (after Parker and Violante, 1993).

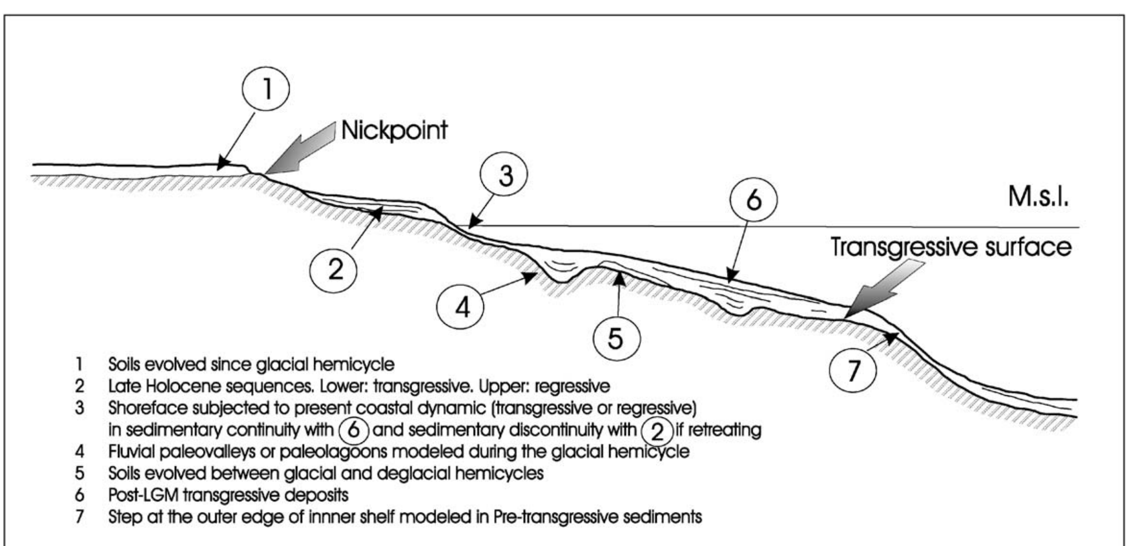

Fig. 9. Schematic cross-section showing the relative position of different parts of the post-LGM depositional sequence and its interrelationships. This figure explains the time-transgressive character of the basal unconformity and the shorewards increasing in the hiatus between pre- and post-transgressive deposits (after Parker and Violante, 1993).

as through textural characteristics when sediments are observed in submarine cores. Pre-LGM sediments are mainly eolian to lacustrine, semiconsolidated, brownish, reddish and tawny loess-like deposits. Paleosols and partially cemented hardgrounds are common features. Fluvial or littoral sands can also be found. Post-LGM sediments are mainly littoral to shallow marine, unconsolidated, yellowish, greenish and grayish sands and muds with variable amounts of shells. Sands in the top of the sequence are considered as relict or palimpsestic. Fining-upwards sandy to silty fluvial deposits with similar colors can also form part of the lowest levels of the sequence.

10. Conclusions

The de la Plata River and adjacent continental shelf and coastal plains were deeply affected by the post-LGM transgression that begun around 18,000 yr ago. Pre-transgressive morphological characteristics allowed for a progressive and uniform covering of the area by marine waters in different environments such as open and protected coasts as well as estuaries. By applying the concepts of seismic stratigraphy, it was possible to differentiate and correlate post-LGM sedimentary records deposited during the transgressive and regressive events both underwater and on the coast, and hence to define the entire unit formed by these processes as a depositional sequence. The unconformity that separates it from former Plio-Pleistocene sequences represents the transgressive surface modeled by the ravinement process, which has in consequence different characteristics depending on the place of observation since it can be located under a marine sequence, below or in between a fluvial sequence or in between a paleosol. As a result, the unconformity is time-transgressive and represents a hiatus that is minimum at the shelf edge and maximum as it approaches the coast.

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