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Submarine evidence of Holocene sea-level fluctuations in the Bahía Blanca estuary, Argentina

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Abstract

Sedimentological and micropaleontological studies were carried out on a core representative of regional submarine outcrops located in the external area of the Bahía Blanca estuary. Three different zones were characterized within the core. The lower core section is composed of sediments deposited in a restricted intertidal environment, such as a coastal lagoon or the upper part of extensive and vegetated tidal flats, whereas sedimentation in the middle section was influenced more by the action of tidal currents, as presently occurs in tidal flats closely related to a channel system. The upper section of the core shows the gradual passage toward modern conditions, in which sand is transported as bedload by strong tidal currents. The characteristics of both the lower and middle sections of the core indicate a relative mean sea level located below that of the present. The lower section probably was deposited before the maximum Holocene transgression, and the age of the core middle section indicates an important negative mean sea-level oscillation that could be correlated with a worldwide climatic change around 2700 yr BP. This finding indicates that relatively short perturbations in global climate could have more important consequences than heretofore has been believed.

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Keywords: Submarine; Bahía Blanca estuary; Holocene

Resumen

Estudios sedimentológicos y micropaleontológicos fueron realizados sobre un testigo representativo de afloramientos submarinos regionales ubicados en la zona exterior al Estuario de Bahía Blanca. Dentro del testigo se determinaron tres zonas diferentes. La sección inferior está compuesta por sedimentos depositados en un ambiente intermareal restringido como una laguna costera o la parte alta de extensas planicies de marea vegetadas, mientras que la sedimentación de la sección media muestra estar más influenciada por la acción de corrientes de marea como ocurre actualmente en las planicies de marea estrechamente relacionadas con un sistema de canales. La sección superior del testigo exhibe el pasaje gradual hacia las condiciones actuales, donde la arena es transportada como carga de fondo por la acción de fuertes corrientes de marea. Las características de las secciones inferior y media del testigo indican un nivel medio relativo del mar ubicado por debajo del actual. La sección inferior se depositó probablemente antes del máximo transgresivo Holoceno, mientras que la edad de la sección media del testigo indica la ocurrencia de una importante oscilación negativa del nivel medio del mar que puede ser correlacionada con un cambio climático global ocurrido alrededor de los 2700 años A.P. Esto indica que perturbaciones relativamente cortas del clima global pueden llegar a tener consecuencias más importantes de lo que hasta ahora se pensaba.

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1. Introduction

The Bahía Blanca estuary is a mesotidal system formed by a 3000 km^2 complex of different sized channels crossing large islands and tidal flats (Fig. 1). Above mean sea level

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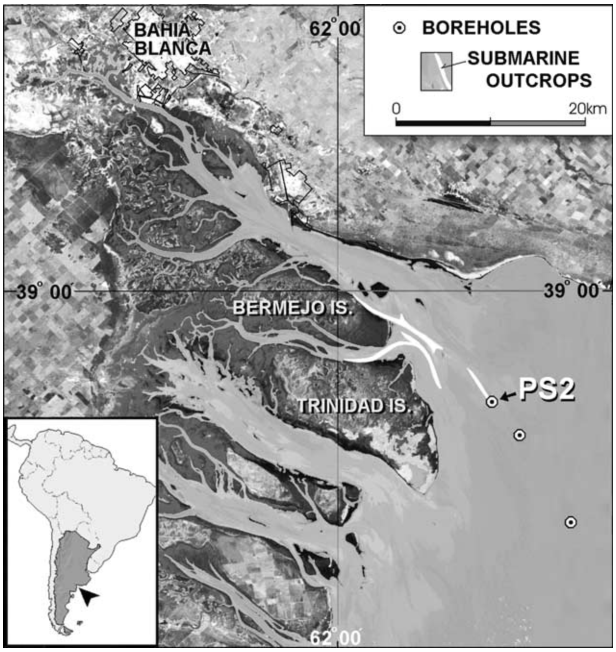

Fig. 1. Studied area. Locations of submarine outcrops and borehole drilled in the external area of Bahía Blanca estuary.

(m.s.l.), the intertidal areas are densely vegetated by *Spartina.* The largest freshwater contributions come from the Sauce Chico River and a smaller stream, the Napostá Grande. The temperature and salinity of the water masses are vertically homogeneous along the estuary. The surface temperature ranges from 21.6 °C during the summer to 8.5 °C in the winter. Superficial mean salinity shows exponential growth from the head of the estuary to the middle portion, where it reaches a value of 27%. The salinity at the distal area of the estuary maintains values between 34 and 35% (Perillo et al., 1987; Píccolo et al., 1988).

The major channels that form the estuary are partly enclosed by highly modified tidal deltas. In its outer area, there is a system of shoreface-connected sand banks (Gómez and Perillo, 1992) that combined with the tidal deltas, results in a constantly evolving and complex bottom topography.

In the Bahía Blanca region and above the m.s.l., Holocene marine deposits are found in the subsurface in places near the present shoreline (González et al., 1983; González, 1989; Aliotta et al., 1987; Farinati and Aliotta, 1987; Aliotta and Farinati, 1990; Farinati et al., 1992). The last Holocene transgression produced a series of sand-shell ridges that are subparallel to the shoreline up to 10 m above the present m.s.l. (González, 1984; Farinati, 1985; Aliotta and Farinati, 1990). However, little is known about the geology of the submerged deposits of the area, probably because of the natural difficulties of studying submarine environments. Only Nedeco-Arconsult (1983), Aliotta et al. (1991; 1992; 1996), Gómez and Perillo (1995); Gómez et al. (1992), and Guerstein et al. (1992) have made any progress on the subject.

At the head of the estuary, on the basis mainly of sedimentological studies, Aliotta et al. (1996) explain the presence of cohesive materials up to 15 m below the present m.s.l. as the result of the postglacial transgression–regression. According to these authors, the maximum Holocene transgression at the Bahía Blanca estuary reached an altitude of 8–10 m above the present m.s.l. at a radiocarbon age of 5990 yr BP (González, 1989), which suggests that after this maximum, the m.s.l. gradually dropped to its present position (Aliotta et al., 1991). However, the total absence of radiocarbon dates and the scarcity of micropaleontological studies carried out on the submarine deposits studied by these authors do not allow the confirmation of this hypothesis.

At the outer estuarine area, by means of bathymetric and side scan sonar surveys and sedimentological analyses of bottom samples, Gómez and Perillo (1995) determined the presence of fine-stratified layers with a large proportion of mud (27–75%). The maximum tidal current speed usually exceeds 1 m/s at the submarine channels, producing a strong bedload transport that prevents the silty-clay sediments settled during slack tide from remaining on the bottom. Therefore, mud deposits do not take place in those deeper areas.

Sand shoal migration elicited the appearance of a series of submarine outcrops at the erosive flanks of the shoals and the channel bottoms (Fig. 1) at depths of up to 15 m below the datum level (16.88 m below m.s.l.). These submarine outcrops appear as linear structures, as shown in side scan sonar sonographs (Fig. 2). The structures are parallel to the isobaths, indicating that they are carved on almost horizontal layers. The cumulative frequency distribution of the superficial samples shows a break between 3 and 5ϕ, indicating that the deposits are composed of populations of fine sand and mud, which thereby suggests alternating environmental energy during the deposition of these materials, as occurs with muddy tidal plains. Without radiometric dates, Gómez and Perillo (1995) tentatively placed the deposition of these materials at approximately 8000 yr BP, before the maximum Holocene transgression, according to the Holocene relative sea level (r.s.l.) curves given by Clark and Bloom (1979a,b) and Suguio and Martin (1980).

TECHNOEXPORT (1990) drilled several boreholes in the Navigation Channel. One of them, PS2, whose top is 12.88 m below m.s.l., was located within the side scan sonar surveyed area (Fig. 1). The most distant borehole was 15 km southeast of the surveyed area. Macroscopic analysis of the cores obtained at these boreholes indicates that the fine-stratified muddy layer deposits mentioned previously are a regional feature. Because of the coincidence in position between the boreholes and submarine outcrops, this study focuses on the sedimentological and micropaleontological analysis of core PS2 as the most representative for

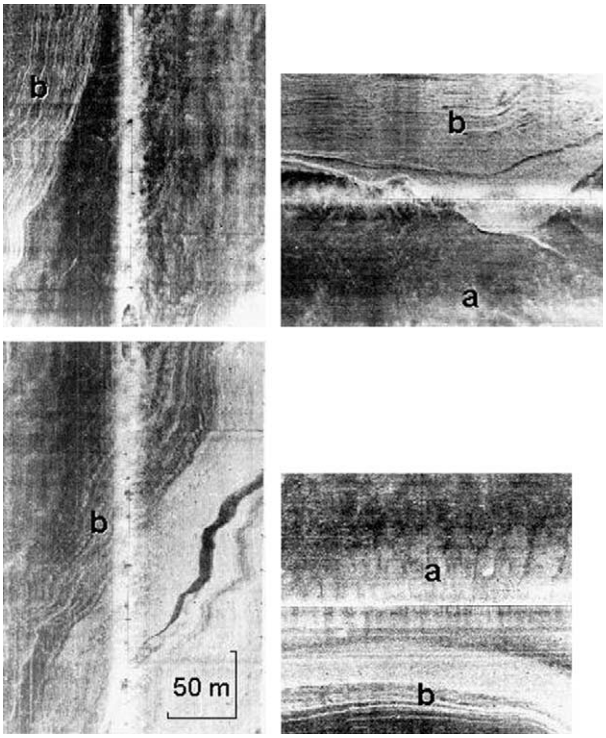

Fig. 2. Examples of side scan sonar records. (a) Loose sand. (b) Submarine outcrops.

determining the paleoenvironmental conditions and chronological significance of these regional features.

2. Methodology

The samples for the micropaleontological studies were taken from the core at 10 cm intervals and washed gently with water through a 230 mesh. For the foraminiferal and ostracoda studies, the number of individuals in 10 g of dry sediment was calculated for each sample. Heusser and Stokes (1984) palynological laboratory procedures were followed, with the exception of aggressive techniques such as acetolysis and oxidation to avoid selective destruction of the dinoflagellate cyst assemblages. Sediment samples were processed according to standard laboratory procedures for grain-size analysis (Folk, 1974).

3. Results

3.1. Lithology

The core shows sections with upward-decreasing grain sizes limited by unconformities that suggest erosional events. Within these sections, it is possible to observe thin alternating layers or lenses, generally, less than 1 cm thick, with a sharp contact between sand and mud (Fig. 3). Even though the core diameter (7.5 cm) does not allow a bedding-type classification (e.g. flaser, lenticular, wavy), the alternating bedding indicates low period oscillations in the depositional environment's energy. Their presence on tidal flats is attributed to tidal action (Reineck and Singh, 1980): Sand layers are deposited during periods of current activity, whereas mud is deposited during stand-still phases of high- and low-water tides (Reineck and Wunderlich, 1967, 1968).

Three major sections can be distinguished within the core. The lower section (370–250 cm) is mainly composed of sandy silt with small intercalations of silty clay, shells, and sand lenses, indicating an almost stable depositional environment. This section probably represents a restricted

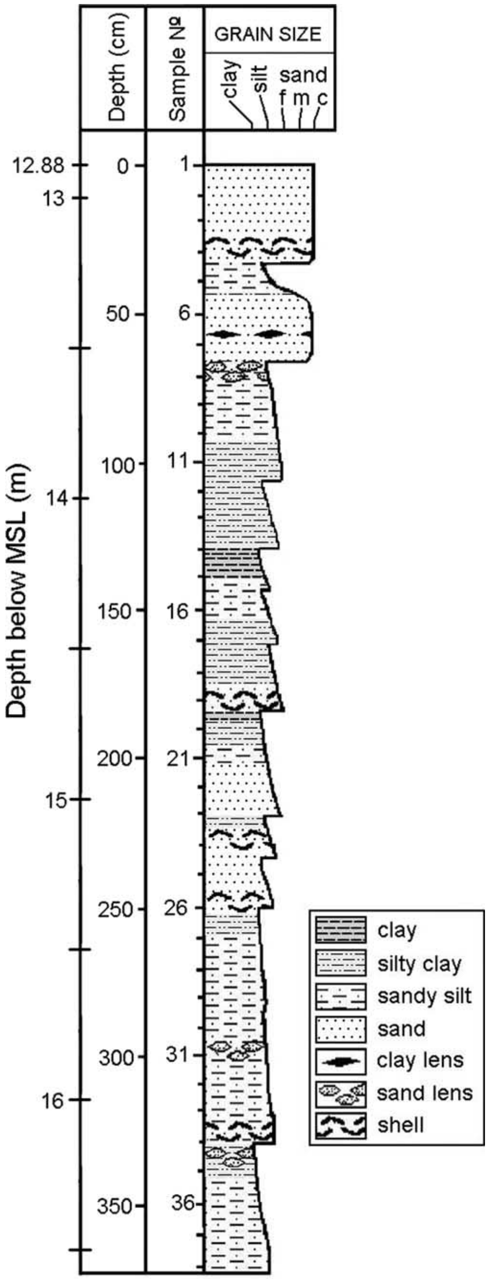

Fig. 3. Sedimentary profile of PS2 core.

intertidal environment (coastal lagoon or upper part of extensive, vegetated tidal flats). The middle section (250–70 cm) shows an alternation of sand, sandy silt, silty clay, and minor layers of clay. Such alternations evince oscillations in the energy of the depositional environment and could be related to ancient tidal flats closely related to a channel system, in which tidal currents and frequent climatic events have a relatively stronger influence on deposition than they do in restricted intertidal environments. The upper section of the core (70–0 cm) is mainly composed of sand with small laminations of silty clay and sandy silt (some clay lenses and shells are also present). This upper section probably represents the gradual passage to the present conditions (40–0 cm), where sand is transported as bedload by the action of strong tidal currents.

3.2. Age of the submarine outcrops

The AMS radiocarbon dating for the lower core section (280 cm) is 6350±40 yr BP (BETA-157180); those for the middle core sections at 160, 150, and 135 cm depth are, respectively, 2460±50 yr BP (BETA-141852), 2350±40 yr BP (BETA-190619), and 2280±40 yr BP (BETA-190620). Because the atmospheric ^{14}C content does not remain constant, these conventional radiocarbon ages should not be taken as sediment absolute ages. Measurements of ^{14}C from absolutely (i.e. dendrochronologically) dated tree rings provide the ^{14}C calibration curve (Stuiver et al., 1998), which reflects numerous minor fluctuations and several major changes in the atmospheric ^{14}C content in the past (~9900 BC).

The Gaussian distribution of an individual date of organic material often corresponds to a rather irregular real calendar age probability distribution, which in some cases encompasses a relatively long period (Van der Plicht et al., 1987). As noted by Van Geel et al. (1996), one of the most pronounced short-lived increases in the ^{14}C content of the atmosphere occurred between approximately 2750 and 2450 yr BP, as a consequence of which around 300 '^{14}C years' elapsed in a period of less than 100 calendar years. During the subsequent 300 calendar years, the '^{14}C age' remained at the level of approximately 2450 BP, forming the so-called Hallstatt plateau in the calibration curve. When PS2 core radiocarbon ages are calibrated to obtain calendar years, the lower core dating becomes cal 7270 yr BP, which represents a period from cal 7300 to cal 7250 yr BP with one standard deviation (68% probability); the 160 cm middle core dating coincides with the Hallstatt plateau, then intercepts the calibration curve at cal 2690, cal 2660, and cal 2485 yr BP (cal 2720–cal 2365 yr BP with one standard deviation).

3.3. Micropaleontology

3.3.1. Ostracods

Qualitative and quantitative information of the Ostracoda obtained from the core sediments enables the definition of three zones and two subzones that represent environmental changes. These zones are defined mostly by the distribution and relative abundance of autochthonous species (adult and juvenile valves; Fig. 4). Furthermore, density and diversity indices, as plotted in Fig. 5, and the relative abundance of allocthonous species (only adult or juvenile forms) have been analyzed. The taxonomic identification has been discussed previously by Bertels and Martínez (1997); Bertels-Postka and Martínez (1999), and Martínez (2002).

Zone OPS2 I (350–255 cm) is dominated by *Loxocythere variasculpta* Whatley, Moguilevsky, Toy, Chadwick, and Ramos, 1997 and *Neocytherideis ruidis* Whatley,

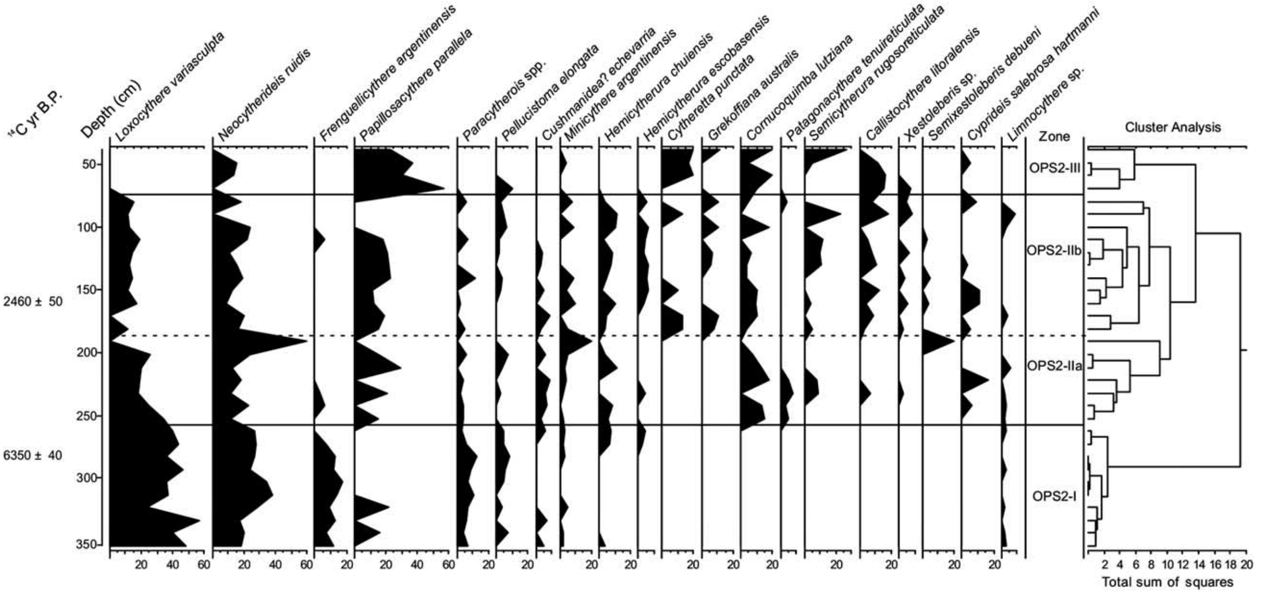

Fig. 4. Distribution of autochthonous species of Ostracoda at PS2 core (including all species with relative frequencies of more than 6%).

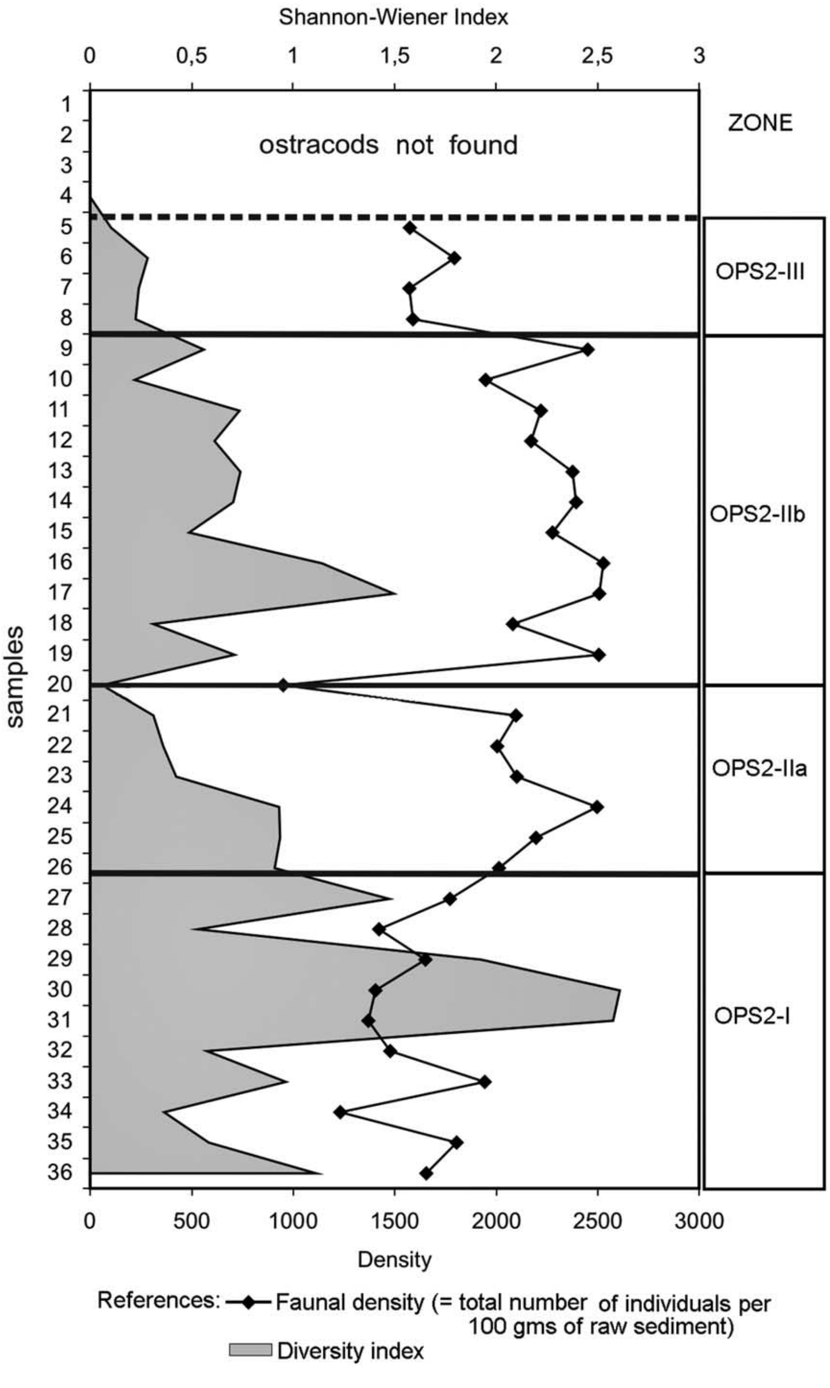

Fig. 5. Faunal density of autochthonous taxa of Ostracoda and the diversity index (Shannon-Weaver information function).

Moguilevsky, Chadwick, Toy, and Ramos, 1998. Although lower in percentage, *Frenguellicythere argentinensis* Bertels-Postka and Martínez, 1999 is important as well. *Papillosacythere parallela* Whatley, Chadwick, Coxill, and Toy, occurs in the lower part of the zone. The abundance of phytal taxa such as *Paracytherois* sp. n., *Paracytherois* sp. n.1, and *Pellucistoma elongata* Whatley, Moguilevsky, Chadwick, Toy, and Feijó Ramos, 1998 is significant throughout the zone.

Most species recorded in this zone live in modern subtidal and intertidal areas of the inner sector of the Bahía Blanca estuary. *L. variasculpta* and *P. parallela* abound within both channel sediment (at 2–4 m depth) and tidal flat areas but are more abundant in the latter. *N. ruidis* live and thrive exclusively in the tidal flats, which in their higher part are vegetated with *Spartina* sp. Other common species that occur only in the tidal flat are *F. argentinensis* and *Paracytherois* sp. n. (Martínez, 2002).

The association of autochthonous ostracods, the structure of total populations (autochthonous and allocthonous forms) with low adult/total valves percentages (3–13%), and the high faunal density values (approximately 3000 specimens per 100 g raw sediment in some levels) suggest a low-energy, shallow, littoral environment. The abundance of phytal taxa of ostracods might be related to the development of vegetated tidal flats. Furthermore, the low diversity according to the Shannon–Weaver index values (<2) and the presence of nonmarine taxa such as *Limnocythere* evince continental water input and unstable salinity conditions.

In Zone OPS2 II (255–75 cm), *Loxocythere variasculpta* and *Neocytherideis ruidis* decrease in abundance compared with Zone I; nevertheless, they remain the main components of the association. *Papillosacythere parallela*, *Hemicytherura chuensis* Kotzian, *H. escobasensis* Bertels-Postka and Laprida, *Minicythere argentinensis* Bertels and Martínez, 1997, and *Cushmanidea? echevarriae* Bertels and Martínez, 1997 are more abundant throughout this interval. Upward, the introduction of mainly marine taxa permits division into two subzones:

Subzone OPS2 IIa (255–190 cm) represents the first occurrence of autochthonous populations of C*ornucoquimba lutziana* Zabert, 1978, *Patagonacythere tenuireticulata* (Kotzian), *Semicytherura rugosoreticulata* Whatley, Chadwick, Coxill, and Toy, *Callistocythere litoralensis* (Rossi de García), *Xestoleberis* sp., and *Cyprideis salebrosa hartmanni*, Ramírez, in this interval.

In Subzone OPS2 IIb (190–75 cm), the autochthonous species are *Cytheretta punctata* Stuiver et al., 1998, *Grekkofiana australis* (Rossi de García), and *Semixestoleberis debueni* Hartmann. Moreover, *Hemicytherura escobasensis* Bertels-Postka and Laprida, *C. litoralensis*, and *Xestoleberis* sp. are more abundant than in Subzone OPS2 IIa.

Most of the species found in this zone live in modern sediments from the Bahía Blanca estuary. *C. salebrosa hartmanni, M. argentinensis*, and *S. debueni* live only in vegetated tidal flats. *C punctata, C. lutziana, S. rugosoreticulata,* and *H. chuiensis* occur exclusively in subtidal areas (2–4 m depth), whereas *C. litoralensis* and *H.* e*scobasensis* are present in both tidal flat and subtidal areas, though they are significantly more abundant in the latter (Martínez, 2002). Thus, the increase of subtidal species in this zone suggests tidal flats influenced more by tidal currents than in Zone I.

The highest diversity of marine taxa and the diversity index values of approximately 2.5 in some levels indicate euhaline salinity conditions. However, the presence of taxa such as *Limnocythere* and *Cyprideis* indicates salinity variations. According to Ornellas and de Würdig (1983) and Días-Brito et al. (1988), the mixohaline ostracod *C. salebrosa hartmanni* lives in shallow environments (0–6 m) with large salinity variations (0–29%). Thus, the association of ostracods recorded throughout this zone may indicate mixed-polyhaline to euhaline conditions (18 to >30‰, according to the 1958 Venice Symposium, Hiltermann, 1985).

In general, the autochthonous ostracod associations recorded in each sample throughout the core with ecologically distinct species represent 'an environmentally condensed fossil assemblage' (Kidwell and Bosence, 1991). The different ecological requirements of the species and the evident fluctuation in ostracod frequencies in this zone are related to the habitat diversity and the hydrodynamic conditions of shallow environments dominated by tidal currents.

The increase of autochthonous marine taxa in the upper interval (Subzone OPS2 Ib) indicates stronger tidal influence and predominant euhaline conditions in comparison with Subzone OPS2 IIa. This faunal characteristic above 170 cm (Subzone OPS2 IIb) correlates with an increase of euhaline allocthonous taxa, displaced from the continental shelf, such as *Loxoreticulatum dictyotos* Whatley, Chadwick, Coxill, and Toy, *Pterigocytherideis* sp., *Echinocytherideis* sp., and *Bythocythere* sp. (Martínez, 2002). This faunal change indicates a stronger marine influence and could be related to a progressive sea-level rise.

Zone OPS2 III (75–0 cm) is characterized by a noticeable drop in faunal density and species diversity. Furthermore, the populations present high adult/total valve percentages (18–29%). Above 40 cm depth, ostracods have not been recorded, and the samples are represented only by carophyte, oogonies, and poorly preserved mollusks. The faunal characteristics and the absence of ostracods in the upper part of the core suggest an increase in the environmental energy.

3.3.2. Foraminifers

The foraminiferal order is represented mainly by the Rotaliina Suborder, and the Textulariina Suborder is absent. Qualitative and quantitative observations indicate three foraminiferal zones. The analysis is based on the relative abundance of species that occur in more than 1% (Fig. 6).

Zone FPS2-I (350–225 cm) is represented mainly by *Buccella peruviana campsi* (Boltovskoy) and *Elphidium discoidale* (d'Orbigny). *Ammonia becarii* (Linnaeus) is also present but in low percentages. Other species—such as *Bolivina pseudoplicata* Heron-Allen and Earland, *B. striatula* Cushman, *B. translucens* Phleger and Parker, *B. variabilis* (Williamson), *Bulimina affinis* d'Orbigny, *Cibicides dispars* (d'Orbigny), *Elphidium articulatum* (d'Orbigny), *E. galvestonense* Kornfeld, *E. gunteri* Cole, *Miliolinella subrotunda* (Montagu), *Quinqueloculina patagonica* d'Orbigny, and *Q. seminulum* (Linné)—also are present in lower percentages. This zone has the highest abundance of individuals (up to 5900 in 10 g of dry sediments), though the species number ranges from 3 to 26 (Fig. 7).

The faunal association of this zone is characteristic of intertidal areas, inner shelf, and saturated-brackish water bodies (Boltovskoy, 1966; Poag, 1978; Boltovskoy et al.,

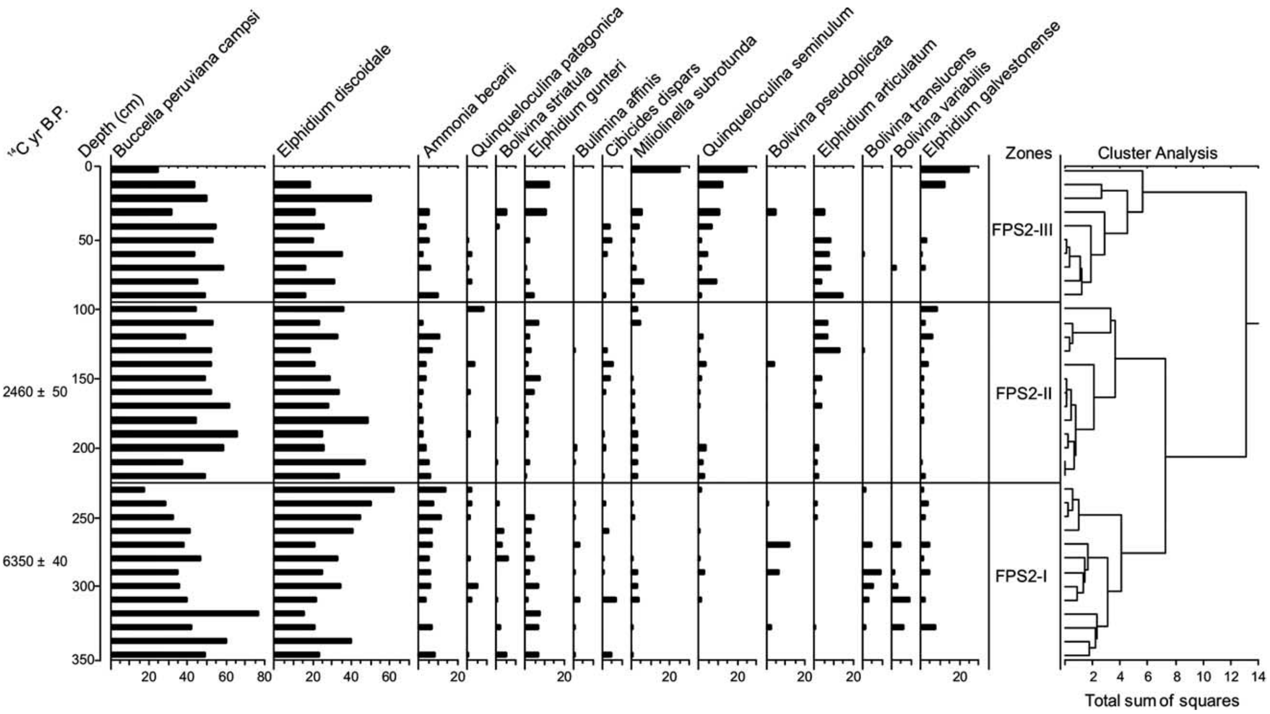

Fig. 6. Distribution of species of Foraminifera at PS2 core.

1980, 1991; Murray, 1991; Alve and Murray, 1995; Cusminsky et al., 1995; Hayward et al., 1996). The fauna is poorly developed, as shown by the low values of the adults/total individuals ratios of *Buccella peruviana campsi*, *Elphidium discoidale*, and *Ammonia becarii*. According to these ratios, the faunal associations represent an abnormal or restricted marine environment (Murray, 1973, 1991).

Zone FPS2-II (225–95) is represented mainly *by Buccella peruviana campsi* and *Elphidium discoidale*. The percentages of *Ammonia becarii, Bolivina striatula, B. pseudoplicata*, and *B. translucens* decrease compared with those in Zone FPS2-I**,** and *B. variabilis* is not found at a depth between 225 and 95 cm. The abundance of individuals in this zone is lower than in the underlying zone (Fig. 7). The development of the individuals of *Buccella peruviana*

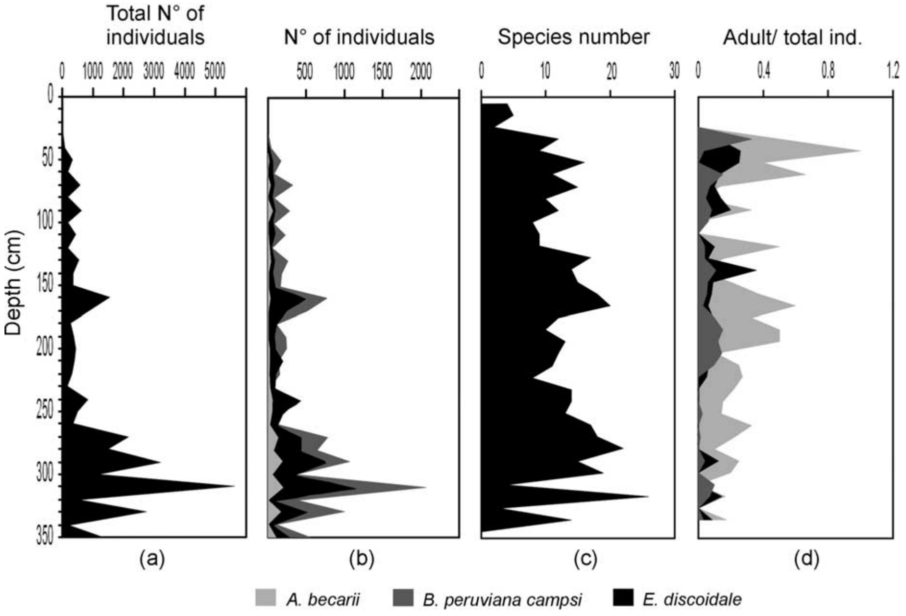

Fig. 7. (a) Total individuals distribution. (b) Number of individuals for species that reach ≧4%. (c) Species number distribution. (d) Adult/total individuals ratio of species that reach ≧4%.

campsi, Elphidium discoidale, and *Ammonia becarii* and the adult/total individuals ratios is higher than in Zone I. Although the number of individuals decreases, this zone presents more favorable conditions for their development, which suggests an increased marine influence.

Zone FPS2-III (95–0) is characterized by high percentages of Buccella peruviana campsi and Elphidium discoidale. Some species such as *Ammonia becarii, Quinqueloculina patagonica, Bolivina striatula, Cibicides dispars, Bolivina pseudoplicata, Bolivina variabilis, and Elphidium articulatum* are present up to a depth of 30 cm. This zone has the lowest individual abundance and species number (Fig. 7). The high adult/total individuals ratios of B. peruviana campsi, E. discoidale, and A. becarii and the presence of well-developed individuals suggest, for the lower part of the zone, increased marine conditions. The upper part (30–0 cm depth) is represented by only four species: *Buccella peruviana campsi*, Miliolinella subrotunda, Quinqueloculina seminulum, and *Elphidium galvestonense*. Thus, the upper part of the core represents the highest energy conditions, probably caused by strong tidal currents.

3.3.3. Palynomorphs

Palynological assemblages are mainly represented by pollen with subordinated amounts of organic walled dinoflagellate cysts (dinocysts) and acritarchs. By means of the cluster analysis stratigraphical constrained approach, version 2.0.b.4 (Grimm, 1991) of the TILIA program, three palynological zones (PPS2-I, PPS2-II, and PPS2-III) and two subzones (PPS2-Ia and b) were distinguished. The analysis is based on dinocysts, acritarchs, and total pollen. Taxa that reached ≧2% are plotted in Figs. 8 and 9.

The pollen spectrum reflects a vegetal community dominated by halophytic taxa, along with low percentages of xerophytic woodland elements (*Ephedra*, *Schinus*, *Prosopis,* and Oxalidaceae) throughout the core. These records are similar to those from modern sediments in the inner area of the Bahía Blanca estuary (Grill and Guerstein, 1995, Fig. 4). The modern pollen samples from the subtidal and intertidal areas are dominated by Chenopodiineae (50–73%), Poaceae (5–20%), and Asteraceae (9–23%).

The dinocyst assemblages, which are not very diverse and are exclusively integrated by gonyaulacacean species, are analogous to the modern assemblages of the inner part of the Bahía Blanca estuary (Grill and Guerstein, 1995). The assemblages from the PS2 core contain dinocyst species typical of temperate estuarine environments of Australia (McMinn, 1991). The taxa present in both the Bahía Blanca and the Australian estuaries are *Operculodinium centrocarpum* (*sensu* Wall and Dale), *O. israelianum* (Rossignol)

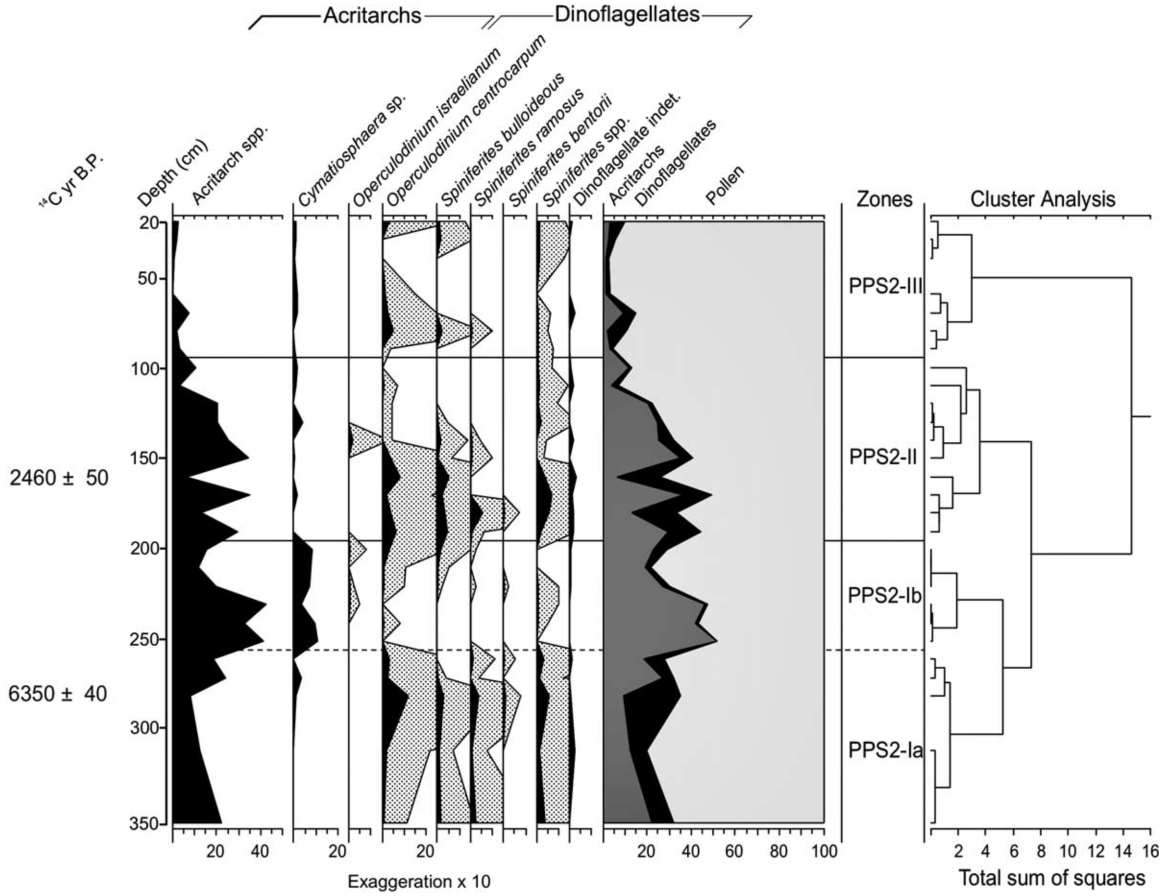

Fig. 8. Marine elements (dinocysts and acritarchs) diagram at PS2 core; the marine elements percentages are calculated over total of palynomorphs.

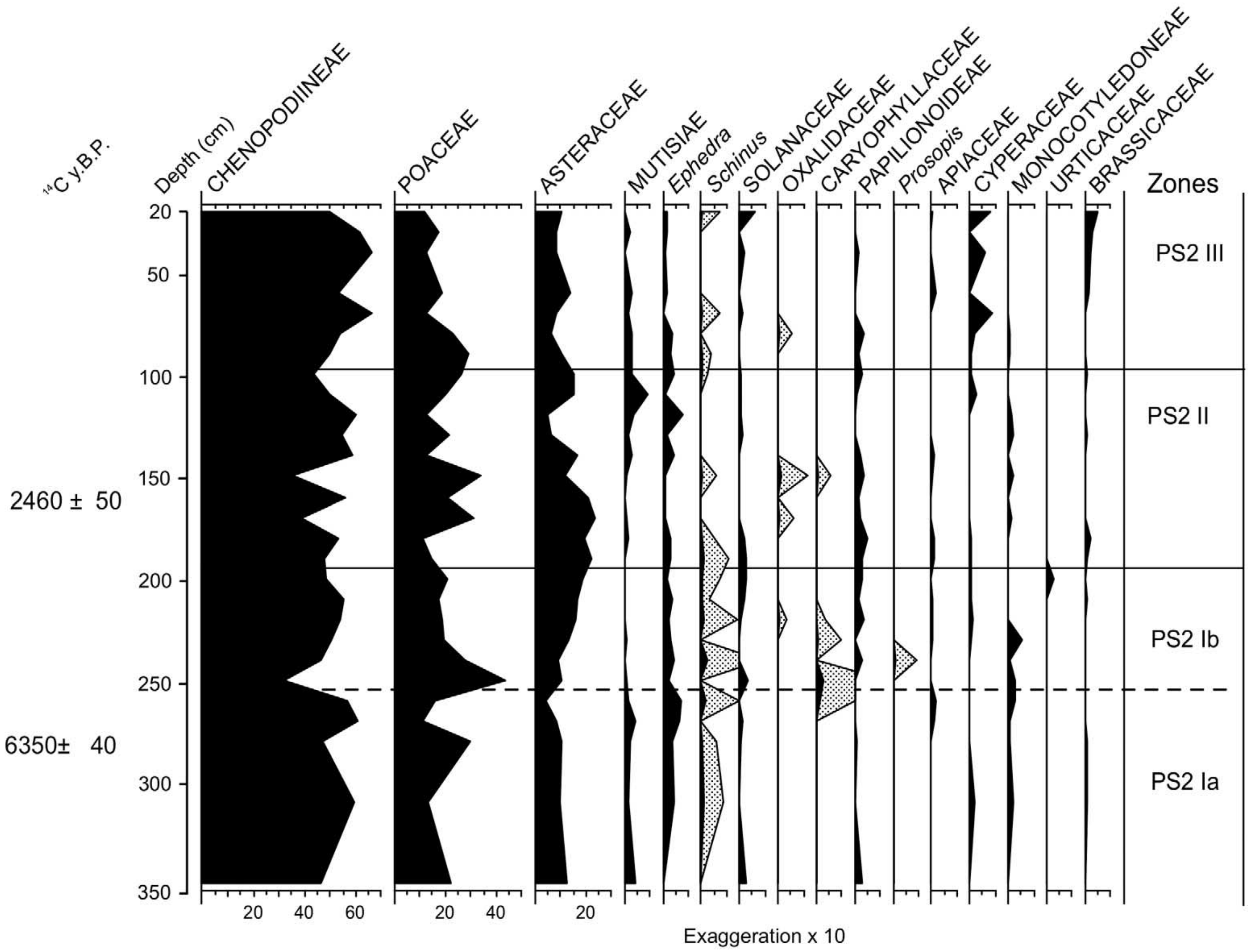

Fig. 9. Fossil pollen diagram at PS2 core; the pollen percentages are calculated over pollen sum.

Wall, *Spiniferites bulloideus* (Deflandre and Cookson) Sarjeant, and *Spiniferites ramosus* (Ehrenberg) Loeblich and Loeblich. The heterotrophic forms represented by *Protoperidinium* spp., which requires nutrient-rich waters, and other estuarine species—such as *Lingulodinium hemicystum* McMinn, 1991 and *Tuberculodinium vamcampoae* (Rossignol) Wall (warm water indicator)—have not been found. Thus, the dinocyst assemblages found in the PS2 core are represented only by autotrophic species that tolerate wide ranges of temperature and salinity.

In Zone PPS2-I (350–195 cm), two subzones were identified. Subzone PPS2-Ia (350–255 cm) is characterized by high values of pollen (up to 80%). Chenopodiineae (47–60%), Poaceae (12–30%), and Asteraceae (<15%) dominate the pollen spectrum and are similar to those of the modern halophytic steppe. The marine elements (dinocysts and acritarchs) reach up to 35% of total palynomorphs. The dinocysts present the highest percentage values (up to 26%), including *Operculodinium centrocarpum*, *Spiniferites bulloideus*, *S. bentorii* (Rossignol) Wall and Dale, 1970, and *S. ramosus*. The small, undifferentiated acritarchs in this study were grouped as Acritarch spp., most of them assignable to *Michrystridium* sp. Low percentages of dinocysts may be related to tidal dynamics that produce turbulence in the column water, which inhibits dinoflagellate production. According to Rochon et al. (1999), the production of some dinocyst species such as *Spiniferites bulloides* and *S. ramosus* is limited mainly by light intensity. Thus, Subzone PPS2-Ia, which includes the highest dinocyst values, suggests relatively high dinoflagellate productivity stimulated by a well-developed photic zone. Such conditions may be related to low-velocity tidal currents.

Subzone PPS2-Ib (255–195 cm) is characterized by a sharp decrease in the dinocyst percentages and the highest acritarch values (up to 50%); *Cymatiosphaera* sp. reaches up to 10% of the palynological spectrum. The pollen spectrum characterized by Chenopodiineae (30–52%) and Poaceae (17–43%) shows an increase in Asteraceae (up to 18%) and xerophytic woodland pollen (<10%). The differences from the spectra recovered from modern halophytic steppe include higher values of Poaceae and Asteraceae and lower values of Chenopodiineae. These records might indicate a major development of intertidal areas vegetated with *Spartina*.

This subzone reflects shallow waters in which dinoflagellate growth would have been inhibited. The high percentages of acritarchs, which represent possible algal spores, suggest an intertidal environment more favorable for the development of these organisms.

Zone PPS2-II (195–95 cm) includes acritarchs (4–35%) and dinocysts (1–23%) with fluctuating percentages. The pollen also exhibits oscillating values: Chenopodiineae (35–60%), Poaceae (10–35%), Asteraceae (5–22%), and Mutisiae (1–10%). A negative correlation between Poaceae and Chenopodiineae and a similar trend between Poaceae and acritarchs are recorded. These spectra might reflect variable water depth conditions. Thus, periods with higher percentages of acritarchs and Poaceae suggest well-developed intertidal areas vegetated with *Spartina*.

In Zone PPS2-III (95–20 cm), there are increased percentages of pollen (up to 95%) with a remarkable decrease in marine elements. The Chenopodiineae are dominant (up to 65%), followed by Poaceae (12–27%) and Asteraceae (<15%). Frequencies of Cyperaceae increase up to 10%. Excluding Cyperaceae pollen, the assemblages of this zone resemble halophytic steppe vegetation. The dinocysts fluctuate between 2 and 8%, and the acritarchs range from 1 to 10%. In modern sediments from the inner Bahía Blanca estuary, dinocysts reach up to 5% and acritarchs vary from 5.5 to 8% (Grill and Guerstein, 1995). Thus, the total spectra, especially between 20 and 50 cm, are closely analogous to the modern assemblages. The reduced values of dinocysts may be related to an increase of energy.

4. Discussion and conclusions

Paleoenvironmental conditions based on sedimentological, micropaleontological, and palynological analyses are summarized in Fig. 10. The lowermost section, dated 6350 ± 40 yr BP in its upper part, reflects a restricted intertidal environment (probably a coastal lagoon or the upper part of extensive and vegetated tidal flats). In the middle section of the PS2 core, dated between 2460 ± 50 and 2280 ± 40 yr BP, sedimentology, microfossils, and palynomorphs indicate oscillating energy and variable salinity and water depth. This section represents ancient tidal flats closely related to a channel system that progressively is more influenced by tidal currents. Thus, the relative m.s.l. was below that of the present at 6350 ± 40 yr BP, as well as after the maximum mid-Holocene transgression during 2500–2300 yr BP. The presence of ostracod and foraminifer species from the inner shelf suggests an increasing sea level toward the top of the middle section related to a gradual change toward present hydrodynamic conditions dominated by strong tidal currents. The geochronological significance of these results and their relationships with regional and global evidence are discussed next.

4.1. Current depth of submarine outcrops related to ancient m.s.l. position

The depth at which the cohesive sediments currently are found does not necessarily represent the real vertical position at which the sediments were deposited, because there are various processes that may have modified it through time. According to Codignotto et al. (1992), glacioeustatic variations during the Holocene in Argentina can be almost totally discarded, because glacier masses that

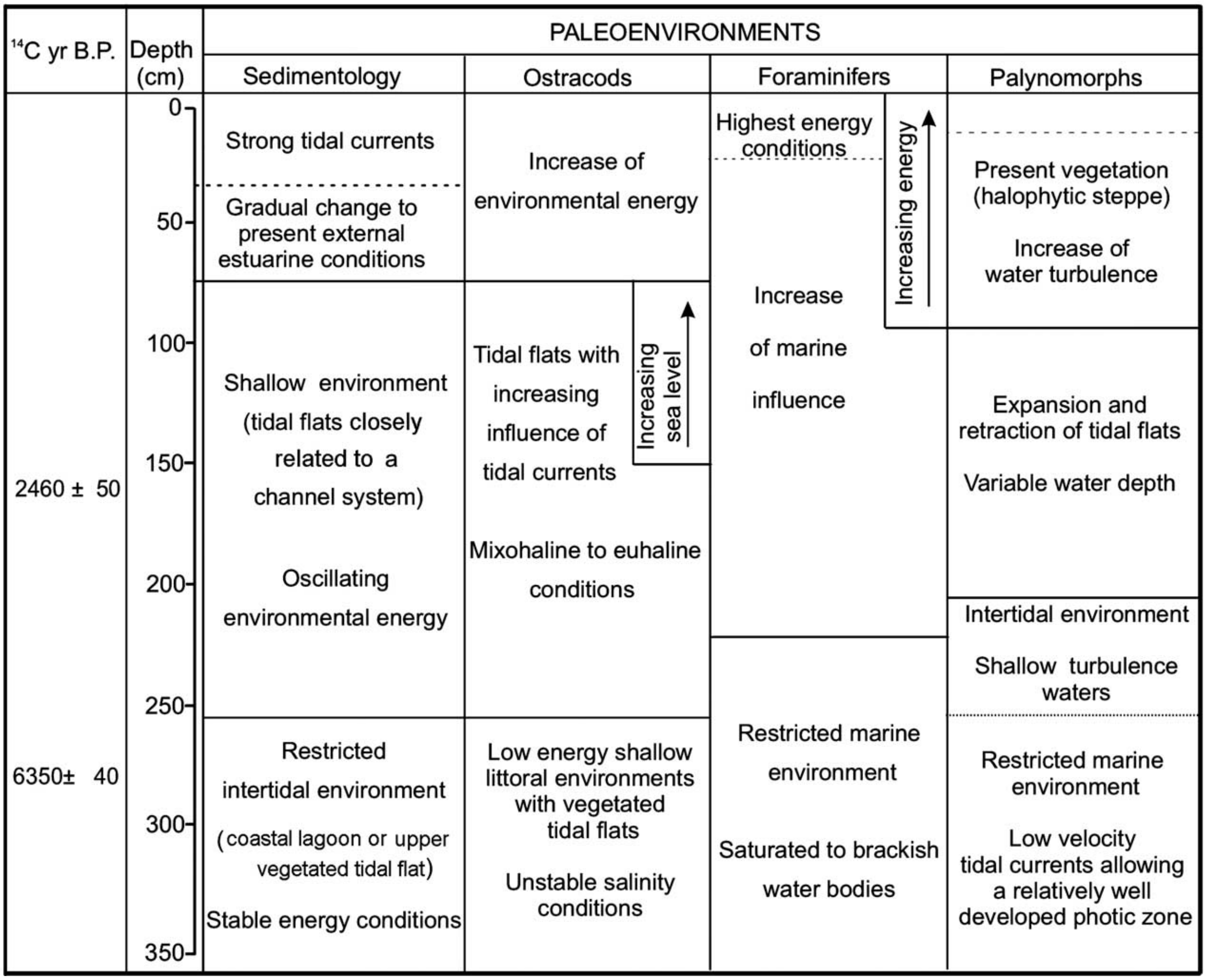

Fig. 10. Summarized paleoenvironmental interpretations at PS2 core.

affected southern Argentina during the Pleistocene had enough time for total isostatic recovery (Mörner, 1990; Bujalesky and González Bonorino, 1990). These authors conclude that the general uplift affecting the Argentinean coasts is caused by neotectonic processes, with minimum values at the basin areas (uplift rate on the order of 0.1 m/1000 yr at the Colorado Basin, where the Bahía Blanca estuary is located) and increasing values at the interbasin zones (up to 1 m/1000 yr in southeast Buenos Aires province). However, it should be mentioned that Rostamini et al. (2000) estimate a constant rate of tectonic uplift for Patagonia of 0.09 m/1000 yr since the middle Pleistocene, though they do not confirm the interpretation of Codignotto et al. (1992) regarding the existence of two distinct uplift rates for basin and interbasin areas.

Depending on the amount of clay and silt, cohesive sediments are expected to suffer an important degree of compaction. Therefore, the whole sediment thickness of a given cohesive material settled several millennia ago and subjected to compression by the weight of supra-laying sediments will appear perceptibly reduced when compared with recently settled sediments. Due to the same process, the vertical position of the cohesive materials will gradually reduce in time, making it impossible to determine the original level of deposition.

Another uncertainty exists regarding the position of the exact altitude of ancient m.s.l. related to the tidal regime. At present, the Bahía Blanca estuary has a mesotidal regime, with a maximum tidal amplitude that varies from 2.4 m at the estuary mouth to more than 4 m at its head and is caused by the estuary's geometry, which can be greatly increased and even doubled due to wind influence (Perillo and Píccolo, 1991). Although it is possible to identify an ancient intertidal environment, the previous geometry of the estuary is unknown; thus, the actual ancient m.s.l. could be located a few meters below or above the studied layers.

However, the depth range at which the studied materials are found is considerably larger than the magnitudes of the inaccuracies in determining the absolute position of the ancient m.s.l. Thus, it is possible to state that the submarine outcrops present in the external zone of the Bahía Blanca estuary and represented by the lower and middle sections of the PS2 core were deposited during an m.s.l. located below the present one.

4.2. Paleoenvironmental changes and m.s.l. variations during the early-mid Holocene

According to Cavallotto et al. (2004) and Violante and Parker (2000), the Holocene postglacial transgression started before 8000 yr BP, surpassed the present m.s.l. position at about 7000 yr BP, and reached its maximum in the Bahía Blanca area between 5900 yr BP (González, 1989) and 4800 yr BP (Aramayo et al., 2002). However, some studies suggest that during the Holocene transgressive hemicycle, the m.s.l. may have followed a more complex pattern. The following paleontological evidence from southern Buenos Aires province agrees with the existence of an m.s.l. below that of the present at approximately 7100 yr BP.

In the southern area of Buenos Aires province (100 km east of Bahía Blanca), early and mid Holocene sea levels below the present m.s.l. were recorded at El Ñandú by Aramayo et al. (2002). These outcrops, located on the present shoreline and dated 8836 ± 65 yr BP (Schillizzi et al., 1992), were interpreted as an aquatic continental environment. Furthermore, in the same area and coincident with the present m.s.l., human paleoichnites discovered in Monte Hermoso were dated 7125 ± 75 and 6705 ± 80 yr BP by Bayón and Politis (1996) and Zavala et al. (1992), respectively, and pollen spectrum and ostracod assemblages suggest the presence of oligohaline shallow-water bodies.

Deposits cropping out at the Quequén Salado River mouth (180 km east of Bahía Blanca city) contain coastal marine gastropods dated 7720 ± 100 yr BP (Farinati and Zavala, 1995). The ostracods and diatoms from levels that overlie the marine deposits indicate a shallow lake unconnected to the sea (Martínez and Gutiérrez Téllez, 1998). Similar results were obtained by Ferrero (1996) for the ostracod assemblages from a section at the mouth of the Quequén Grande River, southern Buenos Aires province (300 km east of Bahía Blanca). These records indicate freshwater to oligohaline shallow environments at approximately 7140 yr BP, which overlie marine sediments dated 7640 ± 100 yr BP.

In the same area, Golfieri et al. (1998) and De Francesco and Zárate (1999), basing their hypotheses on bivalves and gastropods, respectively, note that the estuarine conditions began after 6800 yr BP with oscillating fluvial and marine influence until 6400–6300 yr BP. The progressive increase of marine conditions developed at around 5300 yr BP. However, these outcrops are located in an interbasin zone, in which the uplifting rate, according to Codignotto et al. (1992), is approximately 1 m/1000 yr. Thus, these sediments, which are 2–3 m above the present m.s.l., may have been deposited up to 7 m below their present position.

According to this information, it seems that during the Holocene transgressive hemicycle, there were episodes in which the m.s.l. oscillated below that of the present. Thus, the lowermost section of the PS2 core, dated 6350 ± 40 yr BP and showing an ancient tidal flat, may be related to a negative m.s.l. oscillation that took place between 7700 yr BP and the mid-Holocene maximum sea level.

However, there is another uncertainty related to the actual age of marine shells, which in Argentina is the most common material radiocarbon dated in the study of Holocene m.s.l. fluctuations. Because seawater has lower contents of ^{14}C than the atmosphere, the organisms that obtain C from the ocean usually show several hundred years of ‘apparent aging’, or the so-called reservoir effect.

Previously, this effect was estimated in Argentina as 630 ^{14}C yr (Albero et al., 1987) and in the Beagle Channel (south of Tierra del Fuego) as 540 ^{14}C yr (Rabassa et al., 1986; 1992). However, the particular location of this area (active seismotectonic setting of the Fuegian Andes and the influx of water from the Pacific Ocean) makes it improper to compare it with the stable tectonic environment of the Atlantic coast.

Because the reservoir effect is unknown for the Argentine Atlantic coasts, a value of 600 ^{14}C yr, as determined by Broecker and Olson (1961) for the Falkland current, has been applied to shells from the Argentine shelf (Guilderson et al., 2000). However, this value must be taken as a tentative maximum, because it might be locally reduced where an important continental water input (without reservoir effect) takes place (e.g. La Plata River).

In contrast, mud deposited in extended intertidal areas, such as those represented by the cohesive submarine outcrops, is cyclically exposed to the atmosphere and influenced by shallow continental water, as is suggested by the presence of Ostracods such as *Cyprideis salebrosa hartmanny* and *Limnocythere sp*. Thus, the reservoir effect on these materials should be considerably smaller than that on marine shells. This effect may explain the apparent lack of coincidence among radiocarbon ages obtained from marine shells, continental vegetation, and the core studied herein.

4.3. Paleoenvironmental changes and m.s.l. variations during the late Holocene

The age and depositional environment of the PS2 core middle section seem to contradict almost all studies performed in Argentina to date. In particular in the Buenos Aires province, most available information agrees that after the maximum Holocene transgression, an almost gradual m.s.l. drop followed (Parker and Violante, 1982; Farinati, 1984; Píccolo et al., 1988 in Pirazzoli, 1991; Aguirre and Whatley, 1995; Gómez and Perillo, 1995; Cavallotto et al., 2004). These studies may have detected no fluctuations of the m.s.l. below the present one because most of the radiocarbon evidence collected to date was obtained from above the present m.s.l.

The data gathered from other investigations carried out in the Bahía Blanca area provide for the possibility of a negative oscillation of the m.s.l. during the late Holocene. González (1989), based on Holocene clastic shelly beach ridges and muddy deposits in the inner part of the Bahía Blanca estuary, identifies five episodes with exceptionally high wave energy between 5990±115 and 3560±100 yr BP. Aguirre and Farinati (2000) record other radiocarbon data in *Littoridina australis* (d'Orbigny 1835) from fossiliferous localities near Bahía Blanca. From their radiocarbon data, the lack of deposits above the present m.s.l. for the period 3560–1890 yr BP is noticeable but does not rule out a high-frequency m.s.l. oscillation below its present position.

González et al. (1983) studied a section cropping out at the mouth of the Napostá Grande Stream in the Bahía Blanca estuary. Over a tidal flat dated 3560±100 yr BP and below an erosive unconformity, they find a paleosol interpreted as a regressive episode. Bertels and Martínez (1990), based on Ostracoda from the same section, suggest the progradation of tidal flats after 3560±100 yr BP and the development of fluvial deposits above the erosive unconformity. The dinoflagellate cysts from the same locality have been analyzed by Grill and Quattrocchio (1996), who note the absence of marine elements near the top of the section, which suggests evolution to continental deposits after 3000 yr BP.

Moreover, data from investigations carried out on the Argentinean and Brazilian coasts agree with, or at least do not contradict, the existence of a negative oscillation of the m.s.l. during the late Holocene. While studying successive beach crest groups at Bahía Solano, southern Argentina (Chubut province), Codignotto et al. (1990) observed the absence of deposits above the present m.s.l. for the period 3940–2430 yr BP, with a decrease of 1.5 m of the r.s.l. between the two youngest groups, which does not exclude the possibility of the m.s.l. being below its current position as the middle section of the PS2 core suggests. Cavallotto et al. (2004) present an r.s.l. change curve for La Plata River that shows a relative m.s.l. above the current one in the past 7000 years. However, these authors offer no radiocarbon data corresponding to the period 2990–1902 yr BP to rule out a negative m.s.l. oscillation. Almost the same trend occurs in the data presented by Schnack et al. (1982) for estuarine deposits in the Mar Chiquita lagoon (southeastern Buenos Aires province), in which no radiocarbon data between 2700 and 1340 yr BP are given.

On the basis mainly of emerging evidence, several investigations of Holocene sea-level fluctuations have been carried out on the Brazilian coast. Martin et al. (1987); Suguio and Martin (1982), Suguio et al. (1985), and Martin and Suguio (1992), using radiocarbon dating and sedimentary, biological, and archeological evidence, establish partial r.s.l. curves for several sectors of the central southern Brazilian coasts since 7100 yr BP. These curves show a maximum m.s.l. at approximately 5100 yr BP, which then drops almost gradually to its present position, but two rapid negative oscillations appear with middle points at 4000 yr BP and 2700 yr BP. Because the only data presented refer to above the present sea level, the magnitude of these proposed negative oscillations below the present m.s.l. cannot be confirmed or inferred. The first proposed negative m.s.l. oscillation on the Brazilian coasts seems contradicted by the information presented by Ybert et al. (2003), who use a study of a coastal paleolagoon to claim that the sea level was continuously higher than at present during 4400–3300 yr BP (cal 4870–cal 3485 yr BP). However, Isla (1989) also noticed an r.s.l. history surprisingly similar to the Brazilian one in Mauritania and Senegal.

Radiocarbon ages of vermitid incrustations on the Brazilian coast, presented by Angulo and Lessa (1997) and Angulo et al. (1999), indicate paleosea levels above the present one for both proposed negative sea-level oscillations. However, when the radiocarbon ages given by these authors are calibrated to obtain calendar years BP, the time ranges are notably amplified. Moreover, because the ^{14}C age remained at the level of approximately 2450 BP for more than 300 calendar years, it is almost impossible to define calendar ages for the ^{14}C ages between 2400 and 2550 yr BP. A similar problem occurs for the period corresponding to the first proposed m.s.l. oscillation because the ^{14}C ages between 4100 and 4200 yr BP also show an uncertainty of approximately 300 calendar years. For both periods of time, it is not possible to rule out the occurrence of negative m.s.l. oscillations below the present sea level on the basis of radiocarbon evidence obtained above the present m.s.l.

The 14 radiocarbon datings employed by Cavallotto et al. (2004) to construct an r.s.l. curve for the La Plata River show an m.s.l. decrease of approximately 2.5 m for two pieces of data (4060 and 4210 yr BP), which suggests the first negative oscillation detected in Brazil. In the inner zone of the Bahía Blanca estuary, among marine deposits above the present m.s.l., Farinati (1985) found shell deposits dated 4200±190 yr BP over an intertidal environment at 3 m below the present m.s.l. Although the author does not mention it, the temporal coincidence between these deposits and the first negative m.s.l. oscillation detected on Brazilian coasts calls out for attention. These coincidences could indicate that the first and second oscillation, though the second to a lesser extent, reached depths below the present m.s.l. on the Argentine Atlantic coast.

4.4. Relationship between m.s.l. drop and global climatic change, 2650 yr BP

On the basis of archaeological and paleoecological evidence, Van Geel et al. (1996) found indications of an abrupt climate change in the Netherlands around 2650 yr BP. Van Geel et al. (1996, 1998a,b, 2000) and Van Geel and Renssen (1998) also provide evidence of a synchronous climatic change in Europe (Great Britain, Poland, Fennoscandia, Germany, France, Italy), North America (Canada, United States), South America (Colombia, Chile, Brazil, Argentina), New Zealand, Japan, the Caribbean (Haiti), central Africa (Congo, Cameroon), and northern Africa (Tunisia), which indicates a climatic change to cooler, wetter conditions in the temperate and boreal zones in contrast with the drier conditions in tropical zones. These authors also state that an abrupt climate change could imply cooling in mid to high latitudes in both hemispheres through the expansion of the polar cells, which possibly resulted in perturbations of the oceanic thermohaline circulation. Van Geel et al. (1996) also note that the abrupt climatic change was synchronous with a sudden and sharp rise in the atmospheric ^{14}C content, which is a strong argument for a reduction in solar irradiation and a simultaneous increase in cosmic ray flux, which in turn may have caused the abrupt global climate change.

Paleoclimatic evidence from southern Argentina also matches this synchronous global climatic change. The northward shift of the climatic zones (‘westerlies’ northward shift) caused by this global cooling would have promoted wetter conditions in the southern Andes of Argentina, thereby causing a simultaneous northward migration of Patagonian dryer conditions. Through pollen analyses of sediment samples from Parque Nacional Perito Moreno (southern Andes of Argentina), Mancini et al. (2002) find an episodic change to cooler and wetter conditions between 2700 and 2000 yr BP that would be related to the expansion of glaciers that occurred at the same time (Clapperton, 1990). In contrast, pollen assemblages from a section in the middle basin of the Sauce Grande River (50 km northeast of Bahía Blanca), dated 2830 ± 90 yr BP, indicate a change to arid and semiarid conditions. A similar aridization for 2610 ± 60 yr BP has been interpreted from pollen data and sedimentary facies from the middle basin of the Napostá Grande Stream, located 70 km west of Bahía Blanca (Quattrocchio and Borromei, 1998).

The temporal coincidence between the global climate change and the m.s.l. drop detected in the PS2 core middle section indicates that both events must be strongly linked. Global cooling may have induced an m.s.l. drop, possibly through a combination of thermic contraction of ocean water, an increase of water accumulated in continental areas, and/or perturbations of the oceanic termohaline circulation. Although the driving forces of m.s.l. variations are beyond the scope of this investigation, the magnitude of the detected m.s.l. drop highlights that relatively short perturbations in global climate could have more important consequences than heretofore has been believed.

The data collected in this study provide the first evidence of m.s.l. oscillations below the current m.s.l. in the region of Bahía Blanca during the Holocene regressive hemicycle. Therefore, and despite the scarce radiocarbon data below the current m.s.l., the convergence of evidence indicates that this is not simply a question of casual coincidences. However, to confirm the data presented herein and ascertain the age and magnitude of the regressive event, further detailed studies and radiocarbon dates from levels below the present m.s.l. are needed.

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References

Aguirre, M.L., Whatley, R.C., 1995. Late quaternary marginal marine deposits and palaeoenvironments from northeastern buenos aires province, Argentina: a review. Quaternary Science Review 14, 223–254.

Aguirre, M.L., Farinati, E.A., 2000. Aspectos sistemáticos, de distribución y paleoambientales de Littoridina australis (D‘Orbigny, 1835) (Mesogastropoda) en el cuaternario marino de Argentina (Sudamérica). GEOBIOS 33 (5), 569–597.

Aliotta, S., Farinati, E., 1990. Stratigraphy of holocene sandshell ridges in the bahía blanca estuary, Argentina. Marine Geology 94, 353–360.

Albero, M.C., Angiolini, F., Piana, L., 1987. Holocene 14C reservoir effect at beagle channel (Tierra del fuego, Argentina republic) Quaternary of South America and Antarctic Peninsula, vol. 5. A.A. Balkema Publishers, Rotterdam pp. 59–71.

Aliotta, S., Farinati, E., Ginsberg, S., 1987. Un nivel conchilífero en el subsuelo de ingeniero White, provincia de buenos aires, Argentina. Proceedings 10° congreso geológico Argentino. Tucumán, Argentina 1, 123–127.

Aliotta, S., Lizasoain, G., Lizasoain, W., 1991. Sedimentología y paleoambientes cuaternarios en el sector interno del estuario de bahía blanca, Argentina. Anales del Instituto de ciencias del mar y limnología. Universidad Autónoma de México 18 (1), 99–107.

Aliotta, S., Lizasoain, G., Lizasoain, W., 1992. Sedimentos subsuperficiales entre puerto galván e ing. white, canal principal del estuario de bahía blanca, Argentina, Proceedings 3° Jornadas Geológicas Bonaerenses, La Plata, Argentina 1992 pp. 213–217.

Aliotta, S., Lizasoain, G., Lizasoain, W., Ginsberg, S., 1996. Late quaternary sedimentary sequence in the bahía blanca estuary, Argentina. Journal of Coastal Research 12 (4), 875–882.

Alve, E., Murray, J.W., 1995. Ecology and taphonomy of benthic foraminifera in a temperate mesotidal inlet. Journal of Foraminiferal Research 24 (1), 18–27.

Angulo, R.J., Lessa, G.C., 1997. The Brazilian sea-level curves: a critical review with emphasis on the curves from parananguá and cananéia regions. Marine Geology 140, 141–166.

Angulo, R.J., Giannini, P.C.F., Suguio, K., Pessenda, L.C.R., 1999. Relative sea-level changes in the last 5500 years in southern Brazil (Laguna-Imbituba region, Santa Catarina State) based on vermetid ^{14C} ages. Marine Geology 159, 323–339.

Aramayo, S.A., Schillizzi, R.A., Gutiérrez Téllez, B.M., 2002. Evolución paleoambiental del cuaternario en la costa atlántica del sur de la provincia de buenos aires, Argentina. Revista Sociedad Geológica España 15 (1-2), 95–103.

Bayón, C., Politis, G., 1996. Estado actual de las investigaciones en el sitio monte hermoso 1, provincia de buenos aires. Arqueología, Buenos Aires 6, 83–116.

Bertels, A., Martínez, D.E., 1990. Quaternary ostracodes of continental and transitional littoral-shallow marine environments. Cour. Forsch. Inst. Senckemberg 123 (2), 141–160 (Frankfurt, Alemania).

Bertels, A., Martínez, D.E., 1997. Ostrácodos holocenos de la desembocadura del arroyo napostá grande, sur de la provincia de buenos aires, Argentina. Revista Española de Micropaleontología 29 (3), 20–69.

Bertels-Postka, A., y Martínez, D.E., 1999. *Frenguellicythere argentinensis*, n. gen. and n. sp. from holocene deposits of estuary of bahía blanca, buenos aires, Argentina. Micropaleontology 45 (4), 394–398.

Boltovskoy, E., 1966. In: Eudeba (Ed.), Los Foraminíferos Recientes (Biología, Métodos de Estudio, Aplicación, Oceanografía), p. 510.

Boltovskoy, E., Giussani, G., Watanabe, S.y., Wright, R., 1980. Atlas of Benthic Shelf Foraminifera fo the Southwest Atlantic. M. Junk pub., The Hague. 58 pp.

Boltovskoy, E., Scott, D.B., Medioli, F.S., 1991. Morphological variations of benthic foraminiferal test in response to changes in ecological parameters: a review. Journal of Paleontology 65 (2), 175–185.

Broecker, W.S., Olson, E.A., 1961. Lamont radiocarbon measurements VIII. Radiocarbon 3, 176–204.

Bujalesky, G.G., González Bonorino, G., 1990. Evidence for a stable sea level in the late holocene in san sebastian bay, Tierra del fuego, Southernmost Argentina, International Symposium on Quaternary Shoreline: Evolution, Processes and Future Changes 1990 p. 9 (La Plata, Argentina).

Cavallotto, J.L., Violante, R.A., Parker, G., 2004. Sea-level fluctuations during the last 8600 years in the la plata river (Argentina). Quaternary International 114 (1), 155–165.

Clapperton, C.M., 1990. Quaternary glaciations in the southern hemisphere: an overview. Quaternary Science Reviews9, 299–304.

Clark, J.A., Bloom, A.L., 1979. Hydro-isostasy and holocene emergence of South America, 1978 International Symposium Coastal Evolution in the Quaternary 1979 pp. 61–76 (São Paulo, Brazil).

Clark, J.A., Bloom, A.L., 1979. The effect of the patagonian ice sheet on relative sea levels along the Atlantic coast of South America: a numerical calculation, 1978 International Symposium Coastal Evolution in the Quaternary 1979 pp. 1–79 (São Paulo, Brazil).

Codignotto, J.O., Césari, O., Beros, C.A., 1990. Morfocronología secuencial evolutiva holocena, en bahía solano, chubut. Asociación Geológica Argentina, Revista XLV (3-4), 205–212.

Codignotto, J.O., Kokot, R.R., Marcomini, S.C., 1992. Neotectonism and sea-level changes in the zone of Argentina. Journal of Coastal Research 8 (1), 125–133.

Cusminsky, G.C., Gomez, E.A., Grill, S.C., Guerstein, G.R., Tumini, L., 1995. Estudio sedimentológico y micropaleontológico preliminar de muestras superficiales del estuario de bahía blanca, provincia de buenos aires. Primeros resultados, Proceedings of the VI Congreso Argentino de Paleontología y Bioestratigrafía 1995 pp. 107–115.

De Francesco, C.G., Zárate, M.A., 1852. Análisis tafonómico de *Littoridina* Souleyet, 1994 (Gastropoda: hydrobiidae) en perfiles holocenos del río quequén grande (provincia de buenos aires): significado paleobiológico y paleoambiental. Ameghiniana 36, 297–310.

Días-Brito, D., Moura, J., Würding, N., 1988. Relationships between ecological models based on ostracoda and foraminifers from sepitiba bay (Rio do janeiro, Brazil). In: Hanal, T., Ikeya, N., Isishizoki, K. (Eds.), Evolutionary Biology on Ostracoda. Its Fundamental and Applications, pp. 467–484.

Farinati, E.A., 1984. Dataciones radiocarbónicas en depósitos holocenos de los alrededores de bahía blanca, provincia de buenos aires, Argentina, Simposio Internacional Sobre Cambios del Nivel del Mar y Evolución Costera en el Euaternario Tardío, Abstract. Mar del Plata, Argentina pp. 27–31.

Farinati, E., 1985. Radiocarbon dating of Holocene marine deposits in the bahía blanca area, buenos aires province, Argentina. Quaternary of South America and Antarctic Peninsula 3, 197–206.

Farinati, E., Aliotta, S., 1987. Malacofauna holocena de un paleodepósito litoral en las proximidades de punta alta, provincia de buenos aires, Argentina, Proceedings 4° Congreso Latinoamericano de Paleontología, Santa Cruz, Bolivia 1987 pp. 574–585.

Farinati, E., Zavala, C., 1995. Análisis tafonómico de moluscos y análisis de facies en la serie holocena del río quequén salado, provincia de buenos aires, Argentina, Proceedings Sexto Congreso Argentino de Paleontología y Bioestratigrafía (Trelew, Argentina) 1995 pp. 117–122.

Farinati, E., Aliotta, S., Ginsberg, S., 1992. Mass mortality of holocene tagelus plebeius (Mollusca, bivalvia) population in the bahía blanca estuary, Argentina. Marine Geology 106, 301–308.

Ferrero, L.A., 1996. Paleoecología de ostrácodos holocenos del estuario del río quequén grande. Ameghiniana 33 (2), 209–222.

Folk, R.L., 1974. Petrology of Sedimentary Rocks. Hemphill, Austin. 182 pp.

Golfieri, G.A., Ferrero, L., Zárate, M., 1998. Tafonomía y paleocología de tagelus plebeius (Lightfoot, 1786) en sedimentos holocenos del río quequén grande, provincia de buenos aires, Argentina. Ameghiniana 35, 255–264.

Gómez, E.A., Perillo, G.M.E., 1995. Submarine outcrops underneath shore face-connected sand ridge, outer bahía blanca estuary, Argentina. Quaternary of South America and Antarctic Peninsula 9 (2), 23–37.

Gómez, E.A., Perillo, G.M.E., 1992. Largo Bank: a shoreface-connected linear shoal at the bahía blanca estuary entrance (Argentina). Marine Geology 104, 193–204.

Gómez, E.A., Martínez, D., Cusminsky, G., Suarez, M., Vilanova, F., Guerstein, G.R., 1992. Estudio del testigo PS2, cuaternario del estuario de bahía blanca, provincia de buenos aires, Argentina. PARTE I: sedimentología y Micropaleontología, Proceedings 3ras Jornadas Geológicas Bonaerenses, Argentina 1992 pp. 39–45.

González, M., 1984. Depósitos marinos del pleistoceno superior en bahía blanca, provincia de buenos aires, Proceedings 9° Congreso Geológico Argentino, Bariloche, Argentina, 3 1984 pp. 538–555.

González, M., 1989. Holocene levels in the bahía blanca rstuary, Argentine republic. Journal of Coastal Research 5 (1), 65–77.

González, M., Panarello, H., Marino, H., Valencia, S., 1983. Niveles marinos del holoceno en el estuario de bahía blanca (Argentina). Isótopos estables y microfósiles calcáreos como indicadores paleoambientales, Proceedings Simposio Oscilaciones del Nivel del Mar Durante el Ultimo Hemiciclo Deglacial en Argentina. Mar del Plata pp. 48–68.

Grill, S.C., Guerstein, G.R., 1995. Estudio palinológico de sedimentos superficiales en el estuario de bahía blanca, buenos aires (Argentina). Polen 7, 40–49.

Grill, S.C., Quattrocchio, M.E., 1996. Fluctuaciones eustáticas durante el holoceno a partir del registro de paleomicroplancton, arroyo napostá grande, sur de la provincia de buenos aires. Ameghiniana 33 (4), 422–435 (Buenos Aires, Argentina).

Grimm, E., 1991. Tilia State Museum. Research & Collection Center, Springfield.

Guerstein, G.R., Vilanova, F., Suarez, M., Cusminsky, G., Martínez, D., Gómez, E.A., 1992. Estudio del testigo P2, cuaternario del estuario de bahía blanca, provincia de buenos aires, Argentina. PARTE II: evaluación paleoambiental, Proceedings 3ras Jornadas Geológicas Bonaerenses 1992 pp. 47–52.

Guilderson, T. P., Burckle, L., Hemming, S., Peltier, W. R., 2000. Late Pleistocene sea level variations derived from the Argentine Shelf. Geochemistry, Geophysics, Geosystems (G3), vol. 1, Paper number 2000GC00098 (6808 words, 4 Fig. 3 tables).

Hayward, B.W., Grenfell, H., Cairns, G., Smith, A., 1996. Environmental controls of benthic foraminiferal and thecamoebians associations in a New Zealand tidal inlet. Journal of Foraminiferal Research 26 (2), 150–171.

Heusser, L.E., Stokes, C.E., 1984. Preparation techniques for concentrating pollen from marine sediments and other sediments with low pollen density. Palynology 8, 225–227.

Hiltermann, H., 1985. Zur methodick, brackwasser-sedimente zu erkennenund zu unterscheiden. A method to recognize and distinguish brackish sediments. Facies 12, 243–252.

Isla, F.I., 1989. Holocene sea-level fluctuation in the southern hemisphere. Quaternary Science Reviews 8, 359–368.

Kidwell, S.M., Bosence, D., 1991. Taphonomy and time averaging of marine shelly fauna. In: Allison, P.A., Briggs, D.E. (Eds.), Taphonomy: Releasing the Data locked in the Fossil Record Topics in Geobiology, vol. 9, pp. 116–209.

Mancini, M.V., Paez, M.M., Prieto, A.R., 2002. Cambios paleoambientales durante los últimos 7.000 14C años en el ecotono bosque-estepa, 47–48^{o} S, Santa Cruz, Argentina. Ameghiniana 39 (2), 151–162.

Martin, L., Suguio, K., 1992. Variation of coastal dynamics during the last 7000 years recorded in beach-ridge plains associated with river mouths: example from the central brazilian coast. Palaeogeography, Palaeoclimatology, Palaeoecology 99, 119–140.

L. Martin, K. Suguio, J.M. Flexor, J. M. L. Dominguez, A. C. S. P. Bittencourt. Quaternary evolution of the brazilian coast. The role of relative sea-level variation and of shoreline drift. In: quaternary coastal geology of West Africa and South America, *UNESCO Reports in Marine Science*, 43 (1987) 97–145

D. E. Martínez. Microfauna (Ostracoda, Crustacea) del Cuaternario de las cercanías de Bahía Blanca, República Argentina. Universidad Nacional del Sur. Doctoral Thesis (Unpublished), p.p., (2002) 378

Martínez, D.E., Gutiérrez Téllez, B.G., 1998. Asociación de ostrácodos y diatomeas del cuaternario de un ambiente transicional del río quequén salado, provincia de buenos aires, Argentina, Abstract VII Congreso Argentino de Paleontología y Bioestratigrafía, Bahía, Bahía Blanca 1998 p. 36.

McMinn, A., 1991. Recent dinoflagellate cysts from estuaries on the central coast of New South Wales, Australia. Micropaleontology 37 (3), 269–287.

Mörner, N.A., 1990. Sea level changes in the tierra del fuego region, International Symposium on Quaternary Shoreline: Evolution, Processes and Future Changes 1990 p. 40 (La Plata).

Murray, J.W., 1973. Distribution and ecology of living benthic foraminiferids, Heinemann Educational Boock 1973. 274 pp.

Murray, J.W., 1991. Ecology and paleoecology of benthic foraminifera, Logman Scientific Technical 1991 p. 397.

Nedeco-Arconsult, 1983. Estudio de dragado del canal de acceso al puerto de bahía blanca, Informe Geotécnico 1983.

Ornellas, L.P., de Würdig, N., 1983. *Cyprideis salebrosa hatmanni* ramírez, F., 1967, a new subspecies from Brazil and Argentina. Pesquisas15, 94–112 (Porto Alegre, Brasil).

Parker, G., Violante, R.A., 1982. Geología del frente de costa y plataforma interior entre pinamar y mar de ajó. Acta Oceanográphica Argentina 3 (1), 57–91.

Perillo, G.M.E., Píccolo, M.C., 1991. Tidal response in the bahía blanca estuary. Journal of Coastal Research 7 (2), 437–449.

Perillo, G.M.E., Píccolo, M.C., Arango, J.M., Sequeira, M.E., 1987. Hidrografía y circulación del estuario de bahía blanca, Argentina, en condiciones de baja descarga Proceedings of 2^{o} Congreso Latinoamericano de Ciencias del Mar, Perú, vol. II 1987 pp. 95–104.

Píccolo, M.C., Perillo, G.M.E., Arango, J.M., 1988. Hidrografía del estuario de Bahía Blanca, Argentina. Revista Geofísica (IPGH, México) 26, 75–89.

Pirazzoli, P.A., 1991. World atlas of holocene sea-level changes, Elsevier Oceanographic Series, vol. 58 1991. 300 p..

Poag, C.W., 1978. Paired foraminiferal ecophenotypes in gulf coast estuaries: ecological and paleoecological implications. Transactions-Gulf Coast Associations of Geological Societies V XXVIII, 395–421.

Quattrocchio, M.E., Borromei, A.M., 1998. Paleovegetational and paleoclimatic changes during the late quaternary in southwestern buenos aires province and southern tierra del fuego (Argentina). Palynology 22, 67–82.

Rabassa, J., Heusser, C.J., Stuckenrath, R., 1986. New data on holocene sea transgression in the beagle channel: tierra del fuego, Argentina. Quaternary of South America and Antarctic Peninsula, vol. 4. A.A. Balkema Publishers pp. 291–309.

Rabassa, J., Bujalesky, G., Meglioli, A., Coronato, A., Gordillo, S., Roig, C., Salemme, M., 1992. The quaternary of tierra del fuego, Argentina: the status of our knowledge, Sveriges Geologiska Undersokning. Ser. Ca, vol. 81 1992 pp. 249–256.

Reineck, H.E., Wunderlich, F.W., 1967. A new method to measure rate of deposition of single lamina on tidal flats and shelf bottoms, 7th International Sedimentological Congress (abstract) 1967.

Reineck, H.E., Wunderlich, F.W., 1968. Clasification and origin of flaser and lenticular bedding. Sedimentology 11, 99–104.

Reineck, H.E., Singh, I.B., 1980. Depositational Sedimentary Environments, second ed. 1980 549 pp.

Rochon, A., De Vernal, A., Turon, J. L., Matthiessen, J., Head, M. J., 1999. Distribution of recent dinoflagellate cysts in surface sediments from the north Atlantic Ocean and adjacent seas in relation to sea-surface parameters. American Association of Stratigraphic Palynologists Foundation Contribution Series Number 35.

Rostamini, A., Peltier, W.R., Magín, A., 2000. Quaternary marine terraces, sea-level changes and uplift history of patagonia, Argentina: comparisons with predictions of the ICE-4G (VM2) model of the global process of glacial isostatic adjustment. Quaternary Science Reviews 19, 1495–1525.

Schillizzi, R.A., Aramayo, S.A., Caputo, R., 1992. Evolución geológica del yacimiento paleoicnológico de pehuen-có (Partido de coronel rosales) provincia de buenos aires, Argentina, Proceedings Terceras Jornadas Geológicas Bonaerenses. La Plata, Argentina 1992 pp. 53–57.

Schnack, E.J., Fasano, J.L., Isla, F.I., 1982. The evolution of mar chiquita lagoon coast, buenos aires, Argentina. In: Colquhoun, D.J. (Ed.), Proceedings of the Symposium: Holocene Sea-Level Changes, Magnitude and Causes, pp. 143–155 (Columbia, S.C., USA).

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J., Spurk, M., 1998. INTCAL98 radiocarbon age calibration, 24,000-0 cal BP. Radiocarbon 40, 1041–1084.

Suguio, K., Martin, A.L., 1980. Estudos sobre as oscilaçoes do nivel marinho quaternario ao logo do litoral brasileiro, Proceedings of the Simposio Sobre Problemas Geológicos del Litoral Atlántico Bonaerense. CIC. Mar del Plata, Argentina pp. 281–298.

Suguio, K., Martin, L., 1982. Progress in research on quaternary sea-level changes and coastal evolution in Brazil. In: Colquhoun, D.J. (Ed.), Proceedings of the Symposium: Holocene Sea-level Fluctuations, Magnitude and Causes, pp. 166–181 (Columbia, S.C., USA).

Suguio, K., Martin, L., Bittencourt, A.C.S.P., Dominguez, J.M.L., Flexor, J.M., Azevedo, A.E.G., 1985. Fluctuações do nível relativo do mar durante o quaternário superior ao longo do litoral brasileiro e suas implicações na sedimentação costeira. Revista Brasileira de Geociências 15 (4), 273–286.

TECHNOEXPORT, 1990. Estudio de sedimentación en el Canal de Acceso al Puerto de Bahía Blanca. Technical Report, 4 vols. Unpublished.

Van der Plicht, J., Mook, W.G., Harper, H., 1987. An automatic calibration program for radiocarbon dating. In: Mook, W.G., Waterbolk, H.T. (Eds.), International Symposium on ^{14}C and Archaeology, 2nd, Proc: PACT.

Van Geel, B., Renssen, H., 1998. Abrupt climate change around 2,650 BP in North-West Europe: evidence for climatic teleconnections and a tentative explanation. In: Issar, A., Brown, N. (Eds.), Water, Environment and Society in Times of Climatic Change. Kluwer, Dordrecht, pp. 21–41.

Van Geel, B., Buurman, J., Waterbolk, H.T., 1996. Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological teleconnections around 2650 BP. Journal of Quaternary Science 11 (6), 451–460.

Van Geel, B., Raspopov, O.M., van der Plicht, J., Renssen, H., 1998. Solar forcing of abrupt climate change around 850 calendar years BC. In: Peiser, B.J., Palmer, T., Bailey, M.E. (Eds.), Natural Catastrophes During Bronze Age Civilizations BAR International Series, vol. 728, pp. 162–168.

Van Geel, B., van der Plicht, J., Kilian, M.R., Klaver, E.R., Kouwenberg, J.H.M., Renssen, H., Reynaud-farrera, I., Waterbolk, H.T., 1998. The sharp rise of Δ ^{14}C ca. 800 cal BC: possible causes, related climatic teleconnections and the impact on human environments. In: Mook, W.G., van der Plicht, J. (Eds.), 16th International ^{14}C Conference, Radiocarbon, vol. 40, pp. 535–550.

Van Geel, B., Heusser, C.J., Renssen, H., Schuurmans, C.J.E., 2000. Climatic change in chile at around 2700 BP and global evidence for solar forcing: a hypotesis. The Holocene 10 (5), 659–664.

Violante, R.A., Parker, G., 2000. El Holoceno en las regiones marinas y costeras del nordeste de la provincia de buenos aires. Revista de la Asociación Geológica Argentina 55 (4), 337–351.

Ybert, J.P., Bissa, W.M., Martins Catharino, E.L., Kutner, M., 2003. Environmental and sea-level variations on the southeastern brazilian coast during the late holocene with comments on prehistoric human occupation. Palaeogeography, Palaeoclimatology, Palaeoecology 189, 11–24.

Zavala, C., Grill, S., Martínez, D., Ortiz, H., González, R., 1992. Análisis paleoambiental de depósitos cuaternarios, sitios paleoicnológico monte hermoso i. provincia de buenos aires, Proceedings Terceras Jornadas Geológicas Bonaerenses. La Plata, Argentina 1992 pp. 31–37.