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Negative Sea Level Oscillation in Bahía Blanca Estuary related to a Global Climatic Change around 2,650 yr B.P.

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ABSTRACT

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Bathymetric and side scan sonar surveys, sedimentological analyses and boreholes carried out in the external zone of Bahía Blanca Estuary, determined the regional presence of cohesive fine-stratified layers cropping out at depths of up to 17 m below the present mean sea level. Sedimentological and micropalaeontological studies carried out on the most representative core give evidence of an alternating environmental energy during deposition as it currently occurs in muddy tidal plains. The lower core section consists of sediments which are deposited in a restricted intertidal environment. The middle section represents an intertidal environment which is more strongly influenced by the action of tidal currents as it currently occurs in tidal flats in close relation with a channel system. The upper section shows the gradual passage to present conditions (strong tidal currents). The core lower section (^{14}C 6350 yr B.P.) could have been deposited before the maximum Holocene transgression while its middle section (^{14}C 2460 yr B.P.) indicates the occurrence of an important negative mean sea-level oscillation that is correlated with evidence emerging from the coasts of southern Argentina and central-southern Brazil. The magnitude of this negative oscillation below the current sea level may be correlated with the worldwide climatic change that occurred around 2650 yr B.P. This suggests that the consequences resulting from relatively short perturbations in the global climate are more important than heretofore believed.

ADDITIONAL INDEX WORDS: *Holocene transgression-regression, ancient tidal flats, sedimentology and micropalaeontology, side scan sonar.*

INTRODUCTION

Bahía Blanca Estuary (Figure 1) is a mesotidal system composed of a 3,000 km^2 complex of channels of different dimensions, that crosses extensive islands and tidal flats with intertidal areas densely vegetated by *Spartina.* Several studies have been carried out on Holocene marine deposits emerged in the estuary although little is known about those located below the present mean sea level (MSL).

ALIOTTA *et al.* (1996) claim that the maximum Holocene transgression represented by sand-shell ridges at the estuary head reached an altitude 10 m above the present MSL. They understand that the presence of the underlying cohesive materials up to 16 m below the present MSL results from the post-glacial transgression-regression. ALIOTTA *et al.* (1991) suggest that after the maximum Holocene transgression the MSL gradually dropped to its current situation. However, it is not possible to confirm this hypothesis because of the total absence of radiocarbon dates and the scarcity of micro-paleontological studies conducted by these authors on the submarine deposits.

In the external area of the estuary, GOMEZ and PERILLO (1995) determined, by means of bathymetric and side scan sonar surveys, and sedimentological analyses of bottom samples, the presence of submarine fine-stratified muddy layers cropping out at depths of up to 16.88 m below the current MSL (Figure 1). These submarine outcrops appear as linear structures (Figure 2) parallel to the isobaths indicating that they are carved on nearly horizontal layers. With no radiocarbon dating, the deposition of these materials has been tentatively situated by these authors before the maximum Holocene transgression, at about 8000 yr. B.P. Several boreholes performed by TECHNOEXPORT (1990) in the external area of the estuary area indicate the regional character of these muddy layers. In the present paper, the sedimentological, micropaleontological and geochronological significance of the most representative core (Figure 1) is analyzed and its correlation with different instances of evidence from Argentina and Brazil is also discussed.

METHODOLOGY

The studied core of 3.70 m penetration was obtained at 12.48 m depth (position 4605310-5669060 in Gauss-Krüger projection). The samples for micropaleontological studies were taken from the core at 10 cm intervals, and subsequently washed gently with water over a 230 mesh. The number of individuals present in 10 g of dry sediments was calculated for each foraminiferal and ostracoda sample. The laboratory palynological procedure followed HEUSSER and STOCK (1984) excluding aggressive techniques, such as acetolysis and oxidation, in order to avoid destroying selectively the dinoflagellate cyst assemblages.

Sediment samples were processed following standard laboratory procedures for grain-size analysis (FOLK, 1974).

RESULTS

Based on sedimentological characteristics and on qualitative and quantitative micropaleontological information, three mayor zones within the studied core were identified. These zones (ZI, ZII and ZIII), which are almost coincident in depth, were identified independently of the disciplines involved in the present study. Results are summarized in Figure 3.

Sedimentology and Chronology

The core shows sections with upward decreasing grain sizes limited by unconformities assigned to erosional events. Within these sections, there are thin sharp-contacting alternating layers or lens less than 1 cm thick of sand or mud, which indicate a depositional environment with low period oscillating energy as occur at intertidal areas.

The ZI section (370-250 cm) is mainly composed of sandy silt with small intercalations of silty clay, shells, and sand lens,

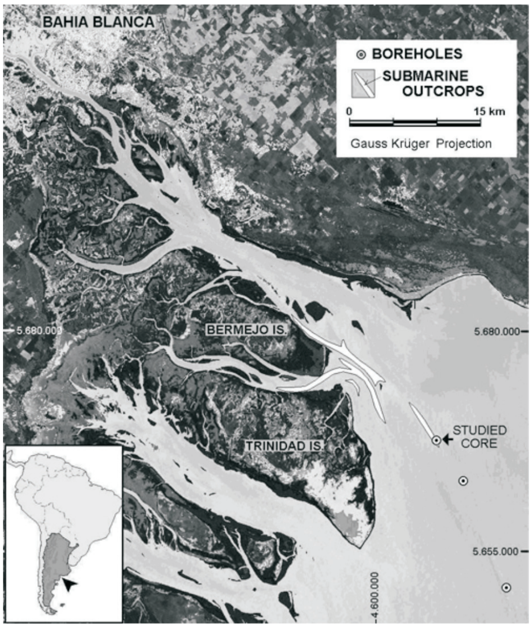

Figure 1. Study area showing the location of submarine fine-stratified outcrops and boreholes.

thus indicating an almost stable depositional environment, probably a restricted intertidal environment (such as an inlet, a coastal lagoon, or the upper part of extensive vegetated tidal flats). The ZII section (250-70 cm) shows the alternation of sand, sandy silt, silty clay, and minor layers of clay which evidence energy oscillations in the environment as those occurring on tidal flats in close relation with the channel system (deposition more strongly influenced by tidal currents and climatic events). The ZIII section (70-0 cm) is mainly composed of sand with small laminations of silty clay and sandy silt, representing the gradual passage to the current conditions (40-0 cm), where sand is transported as bedload as a result of the action of strong tidal currents.

The AMS radiocarbon dating for ZI (280 cm) and for ZII (160 cm) are 6350±40 yr B.P. (BETA-157180) and 2460±50 yr B.P. (BETA -141852), respectively. When these radiocarbon ages are calibrated to obtain calendar years, the ZI dating becomes cal 7270 yr B.P. (cal 7300-cal 7250 yr B.P. period, considering one standard deviation); while the ZII dating coincides with the so-called "Hallstatt plateau", intercepting the calibration curve at cal 2690, cal 2660 and cal 2485 yr B.P. (cal 2720-cal 2365 yr B.P. period, considering one standard deviation).

Micropaleontology

Ostracods

ZI (350-255 cm): Most of the species studied in the present research live in modern subtidal and intertidal areas from the inner zone of Bahía Blanca Estuary. *Loxocythere variasculpta* and *Papillosacythere parallela* abound either within channel sediment (at 2-4 m of depth) or tidal flat areas, being more abundant in the latter. *Neocytherideis ruidis* lives and thrives exclusively in the tidal flats which are vegetated mainly with *Spartina* sp. The association of autochthonous ostracods, the total population structure (autochthonous and allocthonous) with low percentages of adults valves (3-13%) and the high faunal density values (up to 3000 specimens per 100 g raw sediment) indicate a low energy shallow littoral environment.The abundance of phytal taxa of ostracods could be related to the development of vegetated tidal flats. The low diversity Shannon-Wiener´s index values (< 2) as well as the presence of non-marine taxa evidence a continental water input and unstable salinity conditions.

ZII (255-75 cm): *L. variasculpta* and *N. ruidis* decrease in abundance although they still remain as the main component of the association. The highest diversity of marine taxa and the

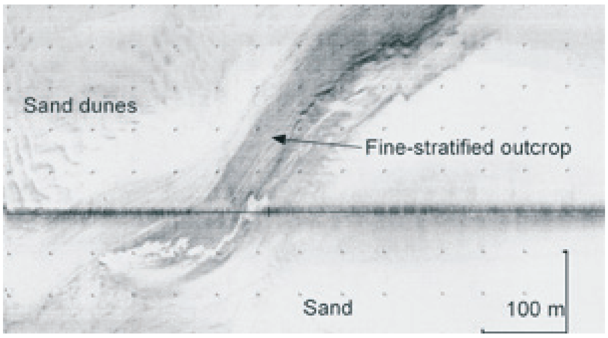

Figure 2. Example of a side scan sonar record showing a cohesive fine-stratified outcrop located at 9 m depth in the study area.

diversity index (2.5) indicate euhaline salinity conditions, but the occurrence of taxa such as *Limnocythere* and *Cyprideis* is indicative of salinity variations. The mixohaline ostracod C. *salebrosa hartmanni* lives in shallow environments (0-6m) with large salinity variation (0-29‰) (ORNELLAS and WÜRDIG, 1983; DIAS-BRITO *et al.,* 1988). The association of ostracods recorded throughout this zone indicates salinity mixe-polyhaline to euhaline conditions. The different ecological species requirements and the fluctuation in frequencies are related to the habitat diversity and to the hydrodynamical conditions from shallow environments dominated by tidal currents.

ZIII (75-0 cm): Exhibits a noticeable drop in faunal density and specific diversity with high percentages of adults valves (18-29%). Above 40 cm depth, the biological characteristics (charophyte oogonies, and mollusks poorly preserved) and the absence of ostracods evidence an increase in the environmental energy.

Foraminifers

This Order is represented mainly by Rotaliina Suborder while Textulariina Suborder is absent.

ZI (350-225 cm): It is represented mainly by *Buccella peruviana campsi* and *Elphidium discoidale*. *Ammonia becarii* is found in lower percentages. This zone has the highest abundance of individuals (up to 5,900 individuals in 10 g of dry sediment) whereas the species number ranges from 3 to 26. The faunal association is characteristic of intertidal areas, inner shelf and saturated to brackish water bodies. The low adults/total individuals ratios and the faunal associations represent an abnormal or restricted marine environment (MURRAY, 1973; 1991).

ZII (225-95 cm): The percentages of *A. becarii, Bolivina striatula, B. pseudoplicata*, and *B. translucens* as well as the abundance of individuals are lower than those in ZI, while the development of *B. peruviana campsi, E. discoidale*, and *A. becarii* and the adults/total individuals ratios are higher. Although the number of individuals decreases, this zone suggests more favorable conditions for the development of individuals, a phenomenon which could be indicative of a higher marine influence.

ZIII (95-0 cm): It is characterized by high percentages of *B. peruviana campsi* and *E. discoidale*,. Some other species disappear at a depth above 30 cm. This zone has the lowest abundance of individuals and the lowest number of species. The high adults/total individuals ratios of *B. peruviana campsi, E. discoidale* and *A. becarii* and the presence of well developed individuals indicates an increment of marine conditions, while the scarcity of species above 30 cm indicates an increase in the environmental energy.

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Palynomorphs

Palynological assemblages are mainly represented by pollen with subordinated amounts of organic walled dinoflagellate cysts (dinocysts) and acritarchs. Pollen spectra, dominated by Chenopodiineae along with low percentages of xerophytic

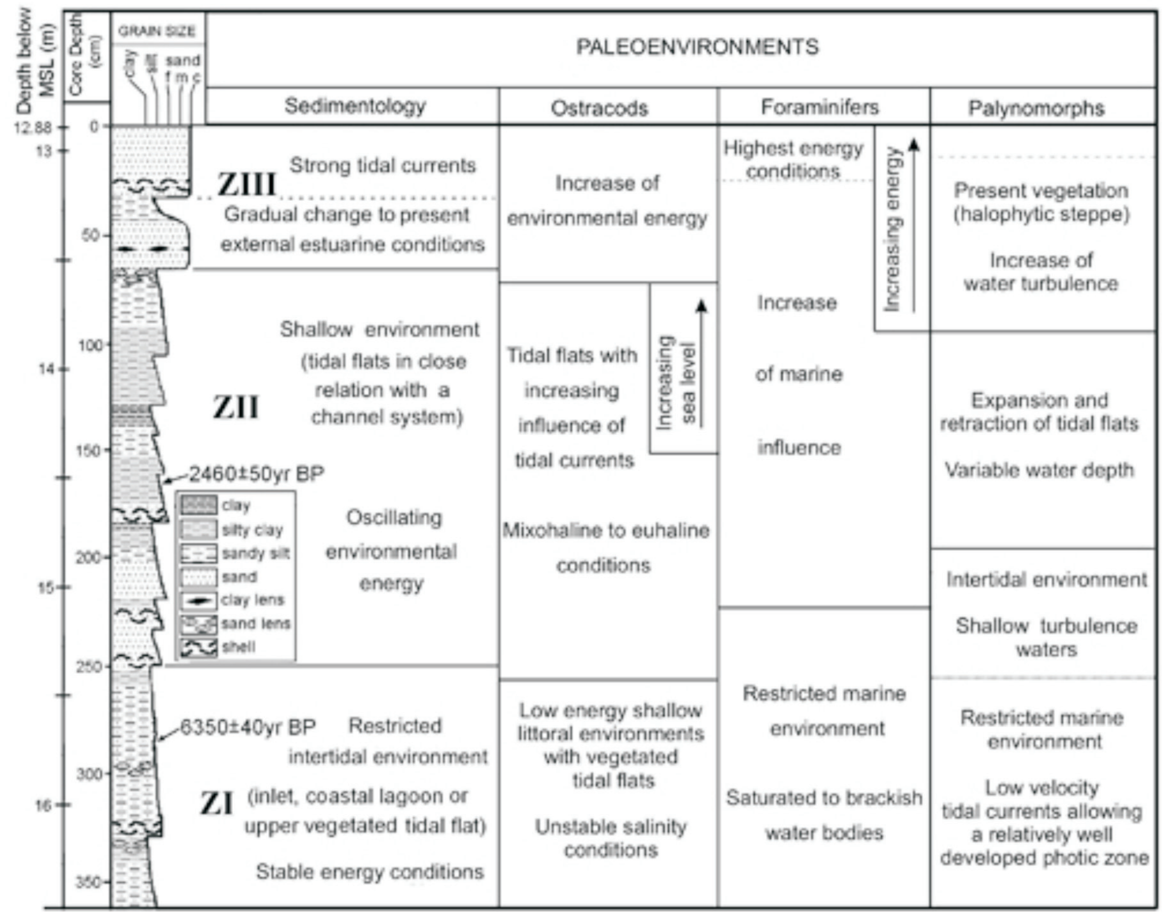

Figure 3. Summary of paleoenvironmental interpretations of the studied core.

woodland elements (*Ephedra*, *Schinus*, *Prosopis* and Oxalidaceae), represents a halophytic steppe. These records are comparable to those from modern sediments of subtidal and intertidal areas at the inner sector of Bahía Blanca Estuary as well as the dinocyct assemblages, poorly diverse and exclusively integrated by gonyaulacacean species (GRILL and GUERSTEIN, 1995). The dinocyct assemblages are only represented by autotrophic species that tolerate wide ranges of temperature and salinity.

ZI (350-195 cm): High dinocyct values present in the lower portion suggest a relatively high dinoflagellate productivity stimulated by a well developed photic zone, the latter being conditions related to low velocity of tidal currents. Upwards there is a notable decrease in the dinocyct percentages, and high values of acritarchs (up to 50%) are observed. The high values of Poaceae and Asteraceae may be indicative of a major development of the intertidal areas vegetated with *Spartina,* reflecting shallow waters where the dinoflagellate growth may have been inhibited.

ZII (195-95 cm): Variable water depth conditions could be reflected by acritarch, dinocyct, and pollen fluctuating proportions. Periods with higher percentages of acritarchs and Poaceae suggest well developed vegetated intertidal areas.

ZIII (95-20 cm): It is characterized by increased percentages of pollen (up to 95%) with a remarkable decrease of marine elements. Higher values of Cyperaceae indicate the presence of freshwater bodies. Total spectra are similar to the modern assemblages from the estuary, while the reduced dinocyct values may be related to an increase in energy.

DISCUSSION AND CONCLUSIONS

The data collected in the present study suggest that the relative MSL was below the current one sometime before 6350±40 yr B.P. and between the maximum mid Holocene transgression and ca 2400 yr B.P. The presence of ostracod and foraminifer species from the inner shelf suggests an increasing sea level towards the top of the middle section related to a gradual change towards the present hydrodynamic conditions dominated by strong tidal currents. In addition, it should be pointed out that the depth at which the cohesive sediments are currently found does not necessarily represent the real vertical position at which the sediments were deposited given that various processes could have modified its relative position. According to CODIGNOTTO *et al.* (1993), glacioeustatic variations are almost totally discarded, with a local neotectonic uplift rate of 0.1 m/1000 yr. Sediment compaction as well as the unknown ancient estuarine geometry which locally modifies the tidal amplitude, produce uncertainties about the ancient absolute altitude of deposition. However, as the depth at which the deposits are located is considerably larger than the uncertainties, it is possible to assess that these materials were deposited during a MSL located several meters below the present one.

There are studies indicating that the maximum Holocene transgression in the area of Bahía Blanca occurred between 5900 yr B.P. (GONZALEZ, 1989) and 4800 yr B.P. (ARAMAYO *et al.*, 2002), however there are evidences (ARAMAYO *et al.*, 2002; BAYÓN and POLITIS, 1996; FARINATI and ZAVALA, 1995 and MARTÍNEZ and GUTIERREZ TELLEZ, 1998; among others) suggesting that during the transgressive hemicycle there were episodes with the MSL oscillating below the present one. Thus, the lowermost section of the studied core (6350±40 yr B.P.) may represent a negative MSL oscillation.

The age of the studied core middle section (2460±50 yr B.P.) seems to contradict almost all the studies conducted in Argentina to date. Since the maximum Holocene transgression, an almost gradual MSL drop without negative fluctuations has been suggested by FARINATI (1985), AGUIRRE and WHATLEY (1995), and CAVALLOTO *et al.* (2004), among others. These ....

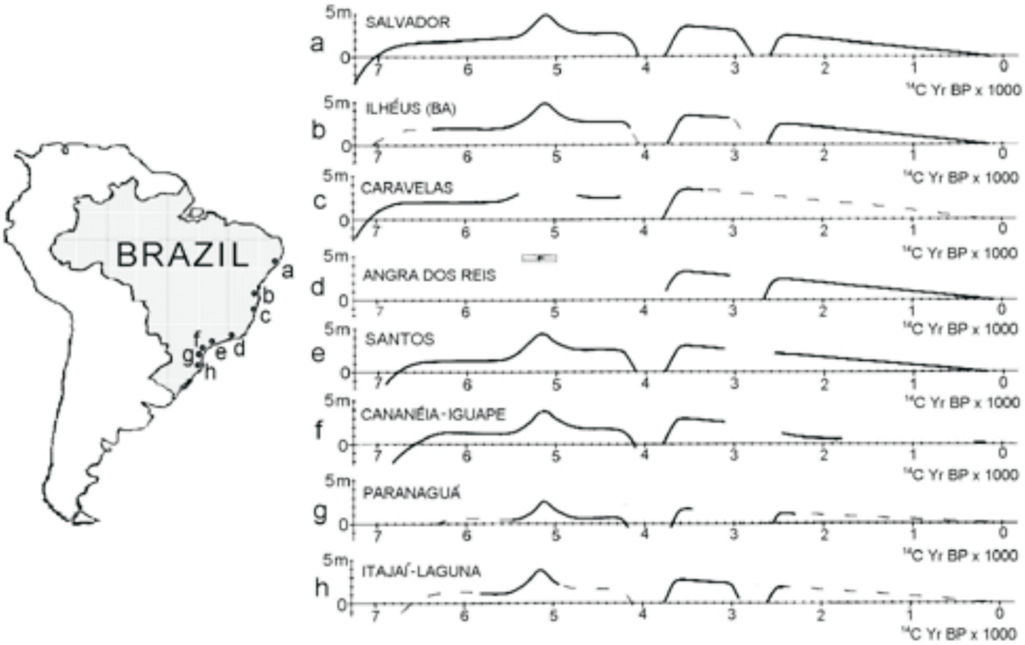

Figure 4. Holocene relative sea-level curves constructed for several sectors of the east and southeast coast of Brazil (modified from Martin *et al*., 2003).

studies may have detected no fluctuations of the MSL below the present one on account of the fact that the majority of the evidence collected to date have been obtained above the present MSL. However, the evidence from the area of Bahía Blanca agree with the possible occurrence of a negative MSL oscillation, namely, the absence of deposits above the present MSL for the period 3560-1890 yr B.P. (AGUIRRE and FARINATI, 2000), a regressive episode at ca.3560 yr B.P. above tidal flats (GONZÁLEZ *et al.*, 1983), progradation of tidal flats after 3560 ± 100 yr B.P (BERTELS and MARTINEZ, 1990), and evolution of continental deposits after 3000 yr B.P. (GRILL and QUATTROCCHIO, 1996). CAVALLOTO *et al.* (2004) presented a curve of relative sea-level changes in La Plata River which shows a relative MSL above the present one for the last 7000 years. However, these authors have no radiometric data corresponding to the period between 2990 and 1902 yr B.P. to rule out the occurrence of a negative MSL oscillation. While studying successive beach crests groups in southern Argentina, CODIGNOTTO *et al.* (1990) observed the absence of deposits above the present MSL for the period 3940-2430 yr B.P.

Several studies carried out on Brazilian coasts mainly based on evidence from above the present MSL, have proposed the occurrence of two high-frequency MSL negative oscillations during the late Holocene (MARTIN *et al.*, 1987, 2003; among others) around 4000 yr B.P. and 2700 yr B.P., respectively (Figure 4); which occurred within the first two periods of Neoglaciar advancements indicated by CLAPPERTON and SUGDEN (1988) for the Andes and Antarctica. Radiocarbon dating presented by ANGULO *et al.* (1999) for the two proposed negative sea-level oscillations indicated paleosea levels above the present one. However, when these radiocarbon ages are calibrated to obtain calendar years B.P. time ranges are notably amplified, augmenting thus the probability for not detecting high-frequency MSL oscillations. In the inner zone of Bahía Blanca Estuary, among marine deposits above the present MSL, FARINATI (1985) found shell deposits dated 4200 ±190 yr B.P superposing an intertidal environment at 3 m below the present MSL. Although this author did not mention it, the temporal coincidence between these deposits and the first negative MSL oscillation detected on Brazilian coasts calls our attention. This coincidence could be indicative of the fact that the first oscillation as well as -though to a lesser extent- the second one, reached depths below the present MSL.

VAN GEEL and RENSSEN (1998) among others, showed evidence of an abrupt global climatic change to cooler conditions around 2,650 yr B.P., and claimed that it may be due to a decrease in solar irradiance. The temporal coincidence between such an abrupt global climate change as well as the occurrence and magnitude of the MSL drop detected in the studied core middle section, suggest that both events are strongly related to each other. Even though the analysis of the mechanisms that made MSL vary to such an extent, goes beyond the scope of the present research, the magnitude of the detected MSL decrease may indicate that the consequences resulting from relatively short perturbations of the global climate are more important than heretofore believed. The data collected in the present study provide the first evidence of an MSL oscillation below the current MSL in the region of Bahía Blanca during the Holocene regressive hemicycle. In view of the above, and in spite of the scarce information below the current MSL, it can be concluded that the convergence of evidence indicates that this is not simply a question of mere casual coincidence.

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