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LATE QUATERNARY MARGINAL MARINE DEPOSITS AND PALAEOENVIRONMENTS FROM NORTHEASTERN BUENOS AIRES PROVINCE, ARGENTINA: A REVIEW

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Abstract — The late Quaternary marginal marine deposits along eastern Argentina (Southwestern Atlantic) are reviewed according to our present knowledge. In the northeastern coastal area of Buenos Aires Province they have been assigned to a series of transgressions and regressions ranging from the late Pliocene to the late Quaternary. The most widely accepted model is Frenguelli's (1957) classical chronostratigraphical scheme of: 'Belgranense', late Pleistocene marine sediments at 3–6 m above m.s.l. and ca. 26,000–>35,000 ^{14}C years BP, the 'Querandinense', Pleistocene–Holocene estuarine sediments below or at present m.s.l., and the most extensive 'Platense', mid-Holocene marine deposits at 4.5–2 m above m.s.l. dated at ca. 8000–1340 ^{14}C years BP.

The restricted 'Belgranense' deposits, recorded in Samborombon Bay, in Magdalena at ca. 32,000 BP, near Mar Chiquita at ca. 24,900 and 30,500 BP and southwards in Bahía Blanca at ca. 26,000–35,500 BP, may belong to an interstadial (González *et al.*, 1986). The molluscan composition suggests a marine invasion of the area but not a typical interglacial cycle characterized by euhaline and warm water elements. However, the oxygen isotope record argues against an interstadial during the interval 34–27 ka and the chronological control for these deposits is very poor, suggesting that they most probably have been elevated neotectonically.

The Pleistocene–Holocene 'Querandinense' deposits, extensively distributed along the Bonaerensian coastal plain and continental shelf (ca. 11,000 ^{14}C years BP), with very low faunal diversity, abundance of freshwater ostracods and absence of the warm water molluscs characteristic of the Holocene ridges, indicate low salinity and cool water conditions. Further dating and isotope analysis of these deposits are required for a better understanding of the chronology of climatic events by the end of the Pleistocene in this area and to establish whether or not they could correspond to the Younger Dryas event of the northern hemisphere.

'Platense' littoral ridges formed between ca. 7600 and 2500 BP extend in several subparallel rows from ca. 34° S to ca. 39° S. They formed either as beaches or possibly as sublittoral bars in Samborombon Bay, where they reach 120 km long, 10–30 m wide and up to 5 m thick at 4.5–5 m above m.s.l., or in the supratidal and intertidal zones in Mar Chiquita at 2–4 m above m.s.l. Molluscs and ostracods suggest a brackish marine to marine brackish environment of lower salinity than the modern Atlantic littoral. During the mid-Holocene, the oceanic waters were mixing with large amounts of Antarctic ice melting in the South Atlantic (Isla, 1990) probably reducing salinity along the Bonaerensian littoral. The oldest littoral ridges accumulated during the Hypsithermal and in the Punta Indio area, their different geometry and alignment, greatest age, highest diversity and warmer affinity of the molluscan fauna suggest a short interval of reversal of the atmospheric circulation pattern.

Further research is necessary for a better understanding of the chronology of the marine late Quaternary deposits, coastal evolution and climatic changes in this area.

INTRODUCTION

During the late Quaternary, shelly marine deposits accumulated over most of eastern South America from Guiana to Brazil and Uruguay. In Argentina they occur from the Río de la Plata to Patagonia and Tierra del Fuego. They have been known since the middle of the last century when D'Orbigny (1834–1847, 1842–1844) described their fossil invertebrates and Darwin (1846) made his general geological observations. In northeastern Buenos Aires Province (Fig. 1) most of the available evidence relates to: chronostratigraphy, lithostratigraphy (Fidalgo, 1979); geomorphology, pedology (Fidalgo *et al.*, 1973; Aliotta and Farinati, 1990; Codignotto and Aguirre, 1993; Tricart, 1973); sedimentology (Spalletti *et al.*, 1987); geochronology (Figini *et al.*, 1984; González *et al.*, 1988a, b); palaeontology (Camacho, 1966; Farinati, 1985a, b; Aguirre, 1991, 1993a).

There remain, however, many gaps in our knowledge

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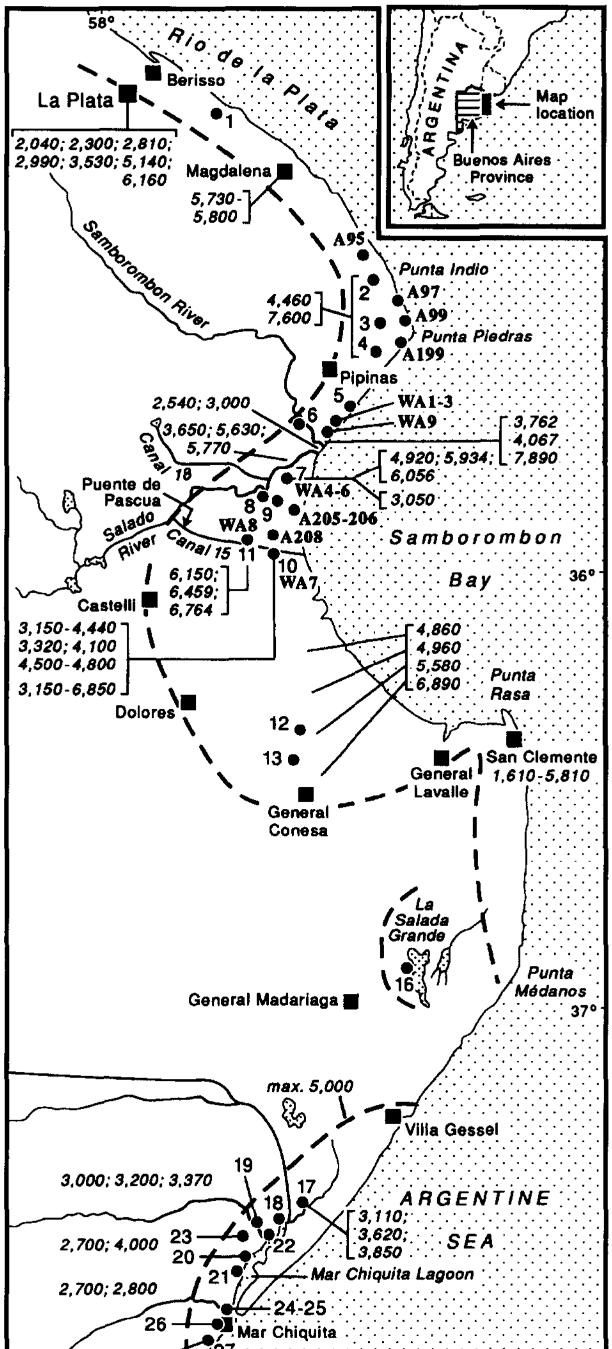


FIG. 1. Location map. Localities studies (1 to 27), micropalaeontological samples (i.e. A95, WA-1, etc.) and radiocarbon dates obtained previously for the study area (source of information in: Codignotto and Aguirre, 1993 and Table 2). -----, westernmost limit of the Quaternary marine transgressions in the area.

of these deposits, especially their origin, number, their relationship to one another and their age. In addition, a palaeoenvironmental synthesis combining molluscan and microfaunal evidence is still wanting.

This paper seeks to present an up to date review based on our present knowledge of the late Quaternary marginal marine accumulations in the northeastern part of Buenos Aires Province and is intentionally focused on the Holocene beach ridges. We add new palaeoecological evidence of the global climatic changes that occurred during the late Quaternary in southern South America (Rabassa and Clapperton, 1990; Iriondo and García, 1993) in agreement with other areas of the southern hemisphere (Avery, 1993; Partridge, 1993) and present additional evidence for a regressive model for their formation (Frenguelli, 1957; Fidalgo, 1979).

AREA OF STUDY

The area considered in this review is shown in Fig. 1 and extends for some 400 km. It is a relatively narrow strip, being widest in the area of Samborombon Bay. The westernmost incursions of the Quaternary sea reached the towns of Castelli and Dolores, some 50 km from the modern coast.

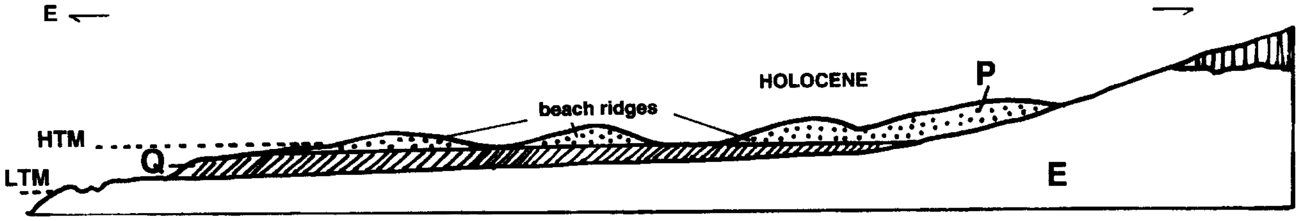
The most widely distributed Quaternary marine deposit is the Las Escobas Formation. This is the youngest of the incursions, being classified within the 'Platense' of Frenguelli (1957) and being mid-Holocene in age (Fig. 2, Table 1). The Las Escobas Formation comprises two facies: the Cerro de la Gloria Member, an extensive series of beach ridges and the Canal 18 Member, more restricted coastal lagoon deposits. These two members have been differentiated by Fidalgo *et al.* (1973) on their morphological relationships and by Aguirre (1993b) on their clastic and biogenic composition.

The Las Escobas Formation, in some areas, lies unconformably on continental sediments of the Pampiano Formation which is of Plio-Pleistocene age (Table 1). Elsewhere is overlies marine sediments of the late Pleistocene Pascua Formation or the coastal lagoon deposits of Destacamento Río Salado Formation. In places, the Las Escobas Formation is overlain by the aeolian sediments of the La Postrera Formation of later Quaternary age (Fidalgo, 1979).

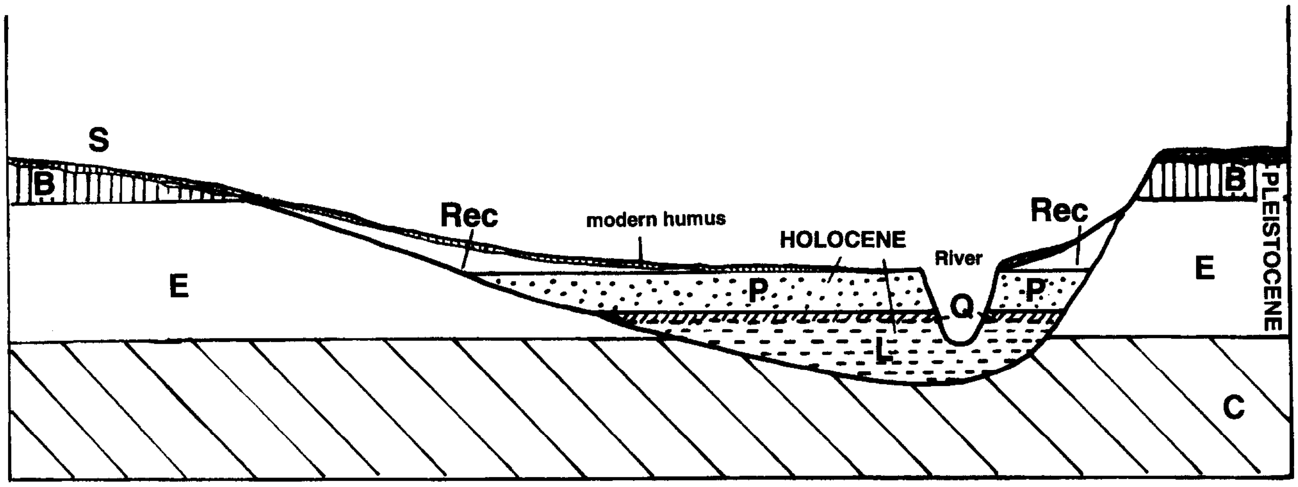
HISTORY OF RESEARCH

Geological Studies

A synthesis of the marine stages of lithostratigraphical units recognized in the Bonaerensian coastal area is shown in Table 1. They have been assigned to transgressions corresponding either to the Pliocene or the Quaternary. Apart from historical records by D'Orbigny (1834–1847, 1842–1844), Darwin (1876), Bravard (1857), Burmeister (1876–1879), Doering (1892) and Ameghino (1889, 1908), that in most cases have no precise geographical or stratigraphical locations, the most



1- Punta Piedras coastal area



2- Bonaerensian oceanic coastal area

FIG. 2. Cross-section showing the 'Querandinense' and 'Platense' *sensu* Frenguelli (1957) in Buenos Aires Province. 1, Rio de la Plata littoral in Punta Piedras area; 2, profile along the Atlantic littoral area of Buenos Aires Province; C = 'Chapadmalense' (continental sediments; upper Pliocene); E = 'Ensenadanse' (continental sediments; middle Pleistocene); B = 'Bonaerense' (continental sediments; late Pleistocene); Q = 'Querandinense' (marshy sediments; Pleistocene–Holocene); L = 'Lujanense' (fluvial sediments; late Pleistocene); P = 'Platense' (marine sediments; mid-Holocene); Rec = Recent sediments, post-Platense; S = modern soil (modified from Frenguelli, 1945; source of information also in Fidalgo *et al.*, 1975).

important works dealing with the late Quaternary marine units are those of Frenguelli (1957), Fidalgo (1979), Fasano *et al.* (1982) and Violante (1988).

Frenguelli (1957) proposed the classical scheme of three marine chronostratigraphical units: the 'Belgranense' (late Pleistocene), 'Querandinense' (latest Pleistocene–early Holocene) and 'Platense' (mid-Holocene) (Fig. 2). Tricart (1973), however, considered all the units in Frenguelli's scheme to be older but his chronology of Querandinense (mid-Pleistocene), Platense (late Pleistocene) and Dunquerkiano (Holocene) is rejected by most recent authors.

The most recent stratigraphical scheme for the area (Fidalgo, 1979) includes: the late Pleistocene Pascua Formation, the Destacamento Río Salado Formation which is terminal Pleistocene to early Holocene, and partially equivalent to the 'Querandinense' of Frenguelli and the mid-Holocene Las Escobas Formation, equivalent to the marine 'Platense' of Frenguelli (Fig. 3, Table 1). Tonni and Fidalgo (1982) tentatively assigned a warmer climate than present to the Las Escobas Formation on the basis of both geological and vertebrate faunal evidence. More recently, Spalletti *et al.* (1987) carried out a sedimentological study of the easternmost Holocene beach ridge in the area of the mouths of the Samborombon and Salado rivers. Codignotto and Aguirre (1993) described various Quaternary geomorphological features, such as barrier islands, barrier spits and marsh and tidal flats in this area, adding radiometric dates for the Holocene deposits of Samborombon Bay and San Clemente coastal areas.

Palaeontological Studies

Molluscs

Previous studies of the Quaternary marine molluscs of Buenos Aires Province date back to the classical monographs of D'Orbigny (1834–1847), Ihering (1895, 1907), Smith (1915, 'Challenger' Expedition) and more recently the catalogues of Camacho (1966). Richards and Craig (1963) worked with material from the 'Vema' Expedition, dealing with the Pleistocene of the neighbouring continental shelf. Carcelles (1944) and Castellanos (1967) dealt with the modern representatives of the bonaerensian marine area. Most taxonomic papers published between 1915 and 1962 refer to only a limited number of taxa or to the mollusca of isolated localities within Buenos Aires Province. Palaeoecological studies have recently been published by Farinati (1984, 1985a) and Farinati *et al.* (1992) for the area of Bahía Blanca in southeastern Buenos Aires province and by Aguirre (1990, 1993a, b) along the northeastern area, between La Plata and Mar de Cobo.

TABLE 1. A history of stratigraphical interpretation of the area

ERA	PERIOD	EPOCH	PALAEOMAGNETIC AGES	"MAMMAL AGES"	MILLIONS OF YEARS	MARINE STAGES OR LITHOSTRATIGRAPHICAL UNITS												
						DOERING 1892	AMEGHINO 1889-1908	GROEBER 1949	BORDAS 1957	FRENGUELLI 1957	TRICART 1973	BUENOS AIRES PROVINCE - ARGENTINA						
												SAMBOROMBON BAY AREA FIDALGO *et al.*, 1975-1982; FIDALGO, 1979 AREA OF THIS STUDY			MAR CHIQUITA AREA FASANO *et al.*, 1982	VILLA GESELL VIOLANTE 1988	BAHIA BLANCA FARINATI, 1985; CHAAR and FARINATI, 1992	COLORADO RIVER DELTA GONZALEZ *et al.*, 196; 1988
												FL	E	M				
CAINOZOIC	QUATERNARY	HOLOCENE	BRHUNES		0.01			SAMBORONBONENSE	BUENOS AIRES FM.: QUERANDI Mb SAMBOROMBON Mb	PLATENSE (regressive) QUERANDINENSE (transgressive)	DUNQUERKIANO Flandrian transgression	ALUVIUM LUJAN FM.: Rio Salado Mb Guerrero Mb	SANDY DUNES LA POSTRERA FM.	LAS ESCOBAS FM.: Cerro de la Gloria Mb Canal 18 Mb	MAR CHIQUITA FM.: Marine Facies Estuarine Facies	MADARIAGA FM.	POSTGLACIAL TRANSGRESSION	PLATENSE (POSTPAMPIAN FM.)
		PLEISTOCENE	MATUYAMA	LUJANIAN ENSENADAN	0.7 2.5	PLATENSE QUERANDINO	PLATENSE QUERANDINO			Bonaerense (FL) BELGRANENSE (M) Bonaerense (FL)	PLATENSE Riss-Wurm & Eemian interglacial QUERANDINENSE Mindel-Riss & Holstein interglacial; transg.	PAMPIANO FORMATION (FL-E) ?		DESTACAMENTO RIO SALADO FM. PASCUA FM. ?			SANGAMON INTERGLACIAL	MID-WISONSIN INTERSTADIAL PLEISTOCENE INTERGLACIAL
	TERTIARY	PLIOCENE	GAUSS	UQUIAN			BELGRANENSE											

REFERENCES:
FL= fluvial sediments
E= eolian sediments
M= marine sediments
?= unknown lower boundary
Modified from Fidalgo and Tonni, 1982; Aguirre, 1990; Tonni et al., 1992; Tambussi et al., 1993

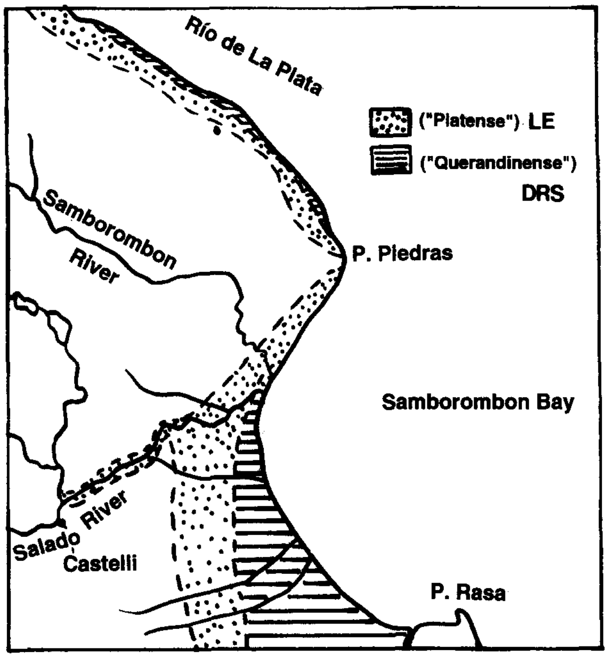


FIG. 3. Distribution of the las Escobas Formation (LE; mid-Holocene; marine transgression) and Destacamento Río Salado Formation (DRS; Pleistocene-Holocene; lower than present sea-level stand) along Samborombon Bay coastal area (after Fidalgo, 1979).

Microfossils

Contributions on the microfauna include Whatley and Cholich (1974) and Valicenti and La Greca and Valicenti and Cholich (*unpublished manuscripts*, MLP) for the Salado Basin area. González *et al.* (1983) studied the area of Bahía Blanca and Espinosa *et al.* (1984) and Isla *et al.* (1986) concentrated on the area of Mar Chiquita, Miramar, Puerto Quequén and the southeastern part of the Buenos Aires Province.

Vertebrates

The remains of marine vertebrates such as *Eubalaena* sp. and the teeth and vertebrate of several groups of fishes have been reported from the Holocene of the area (Las Escobas Formation; Tonni *et al.*, 1981; Tonni and Cione, 1984).

LOCALITIES STUDIED

Pleistocene Localities

The distribution of the marine Pleistocene along the coastal area of Buenos Aires Province is very restricted. Therefore, the Pleistocene deposits sampled or discussed

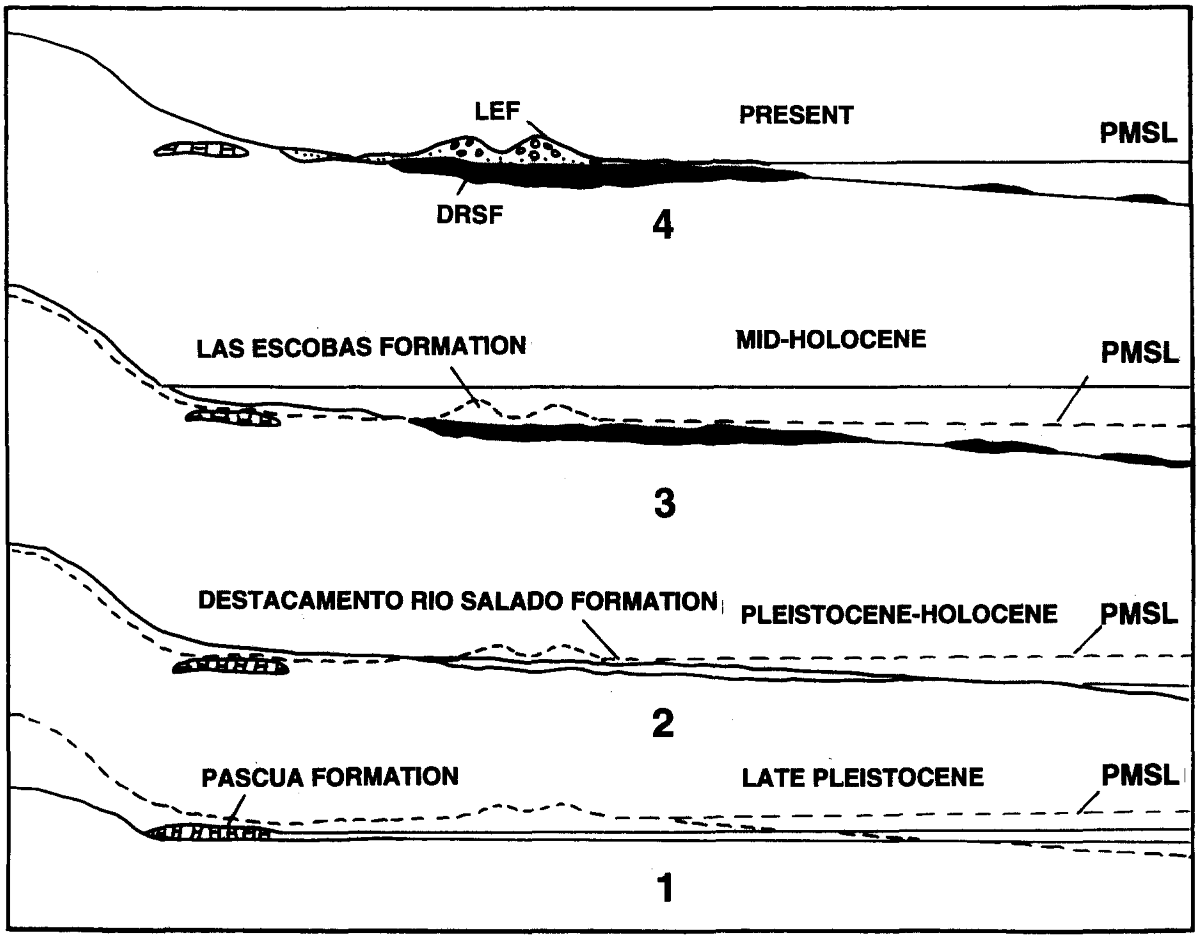


FIG. 4. Sea-level changes occurred along the northeastern Bonaerensian coastal area during the late Quaternary. PMSL = present mean sea-level; 1 = Pleistocene high sea-level (Wisconsinan interstadial?; 'Belgranense', Pascua Fm. = PF); 2 = Pleistocene–Holocene low sea-level stand ('Querandinense', Destacamento Río Salado Fm. = DRSF); 3 = mid-Holocene higher than present sea-level stand ('Platense', Cerro de la Gloria Member of las Escobas Fm. = LEF); 4 = present landscape (modified from Fidalgo, 1979).

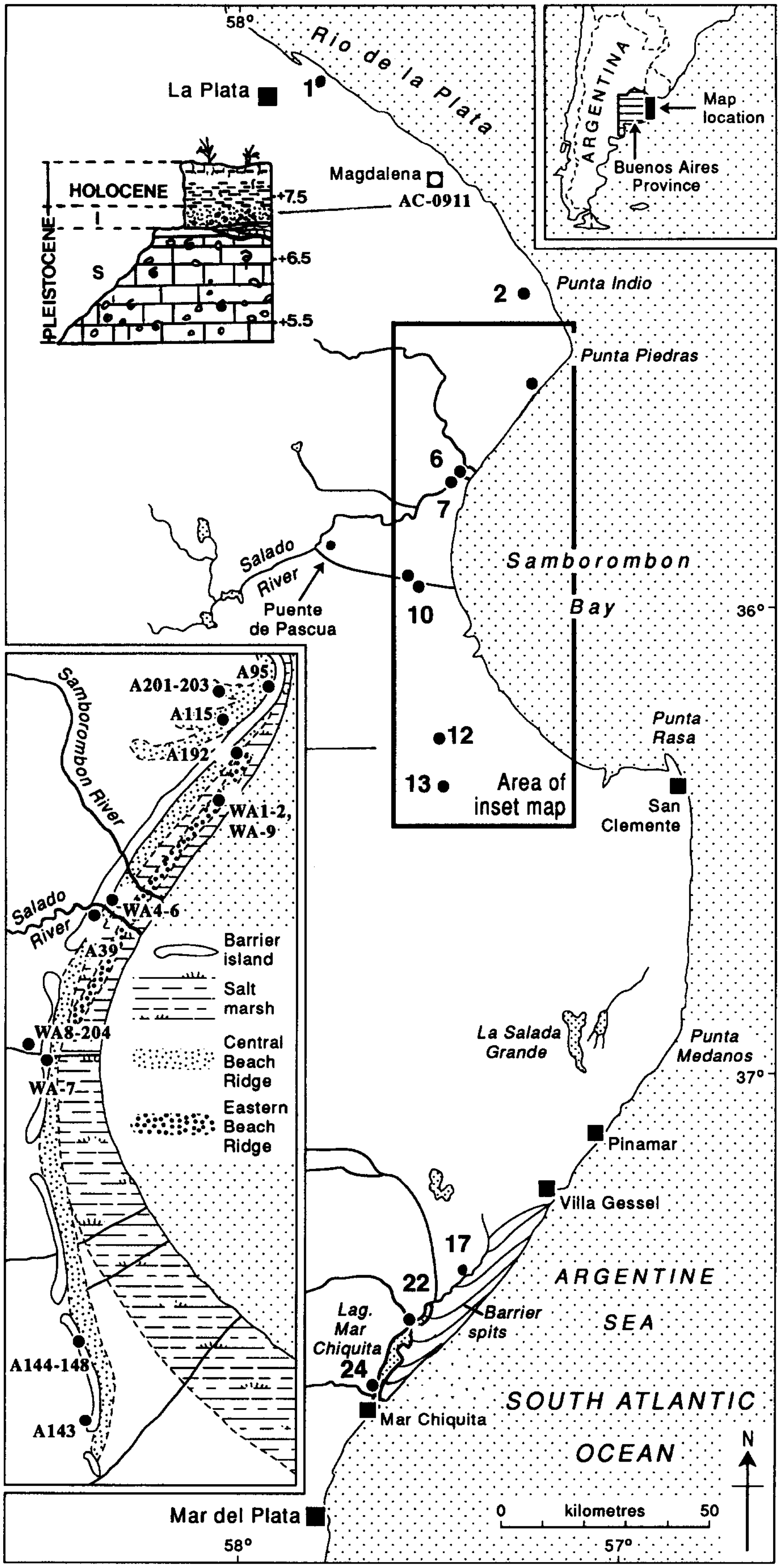


FIG. 5. Holocene marine landforms along the Bonaerensian northeastern coastal area (after Codignotto and Aguirre, 1993). Numbers relate to quantitatively studied localities. Pleistocene deposits from Magdalena: I = Wisconsinan Interstadial (sample AC-0911; ca. 32,000 ^{14}C years BP; INGEIS); S = Sangamon Interglacial. Height in m above present m.s.l. (after Weiler *et al.*, 1988).

are less abundant compared to the more extensive Holocene beach ridges (Fig. 4). The localities of Magdalena and Puente de Pascua (Figs 1 and 5) were analyzed in more detail as they have provided abundant shell material and have some common species with the Holocene ridges. This has allowed comparison between their respective palaeoenvironments.

Our knowledge of the marine Pleistocene of the area is very incomplete and requires further studies and better chronological control.

Pleistocene–Holocene

The Destacamento Río Salado Formation, extending along the Bonaerensian coastal area (Fig. 3) and continental shelf (Fidalgo, 1979; Richards and Craig, 1963), was sampled where it underlies the Holocene beach ridges at locality 7 in a natural exposure in the bank of the Salado River (Figs 1 and 7).

Holocene

The Holocene marine landforms (Fig. 5) as described by Codignotto and Aguirre (1993), Schnack *et al.* (1982) and Violante (1988) correspond to barrier islands or beaches (Samborombom Bay) and barrier spits (Mar Chiquita) mostly formed during the last ca. 7000 years. The marine Holocene was sampled in 27 localities (Fig. 1) for faunal analysis and a systematic collection of more than 160 samples was carried out between Punta Indio and Mar Chiquita, mainly in natural exposures of ancient beach ridges of the Cerro de la Gloria Member of the Las Escobas Formation. Molluscs were obtained from each differentiated level (A samples; Figs 6–9) through detailed profiles measured in all the localities. Figures 6–9 show only the most important ones. A detailed description of the localities is given in Aguirre (1993b).

Most of these localities are dated by radiocarbon and amino acid methods, a synthesis of which is given in Tables 2 and 3, while a quantitative analysis in 14 localities, representative of the whole area (Figs 10 and 11), was performed to facilitate the palaeoenvironmental reconstruction based on the biogenic content. Locality 1 in the La Plata suburb of Berisso (Fig. 1) has been included in this study to provide supplementary information on the ages, molluscan associations and palaeoecology of the Holocene ridges which extend northwards of Punta Indio, as well as to control the environmental changes assumed for the area of study in relation to the present conditions obtaining in the Río de La Plata littoral.

STRATIGRAPHY AND PALAEOENVIRONMENTS

The available data on the age and stratigraphy of the marine Quaternary of Buenos Aires Province are inadequate. The position of the Plio-Pleistocene and Pleistocene–Holocene boundaries has not been adequately defined in the area (Pascual and Fidalgo, 1972; Whatley and Cholich, 1974). Mammal ages, based on the not inconsiderable mammalian fauna known from these deposits, especially the continental intercalations, have been used by Pascual *et al.* (1965) to create a biostratigraphy for the region. More modern works by Pascual and Ortiz Jaureguizar (1990), Tonni *et al.* (1992) and Tambussi *et al.* (1993), dealing with the recognition of 'South American land mammal ages' or SALMA and the avifauna, seek to refine this but in many cases vital specimens are housed in local museums and often lack proper stratigraphical control.

No similar biostratigraphy has been attempted using marine invertebrates and, while most authors agree that there were two transgressions in the late Pleistocene and another in the mid-Holocene, there is a great lack of detail concerning their dating, their geomorphology and their environment of deposition.

The three units of the classical stratigraphical scheme of Frenguelli (1957) are outlined in summary below.

'Belgranense' Stage

These are deposits originally defined by Ameghino (1908) as being of Pliocene age (Table 1). They are made up of unconsolidated but mostly cemented shells, similar to the Miocene Patagonian Formation of southern Argentina. Their type locality forms a prominent ridge in the district of Belgrano (Buenos Aires city), known as the Barrancas (cliffs) de Belgrano and they extend southwards to Bahía Blanca (ca. 39° S). This unit is geographically more restricted than the younger marine units, reaching 1 to 4 m thick and is situated between 3 and 6 m above the present day Rio de La Plata coastline, except in Punta Piedras where it is situated at 10 m. On the basis of the mineralogical and sedimentological data, however, differentiation of the Belgranense from the Holocene marine deposits is virtually impossible (Cortelezzi and Lermann, 1971; Fidalgo and Tonni, 1982).

Fidalgo *et al.* (1973) recognized these deposits at Puente de Pascua, in the area of canal 15 (Fig. 1) at some 2–3 m above m.s.l. and named them the Pascua Formation (Fig. 4). They occurred interbedded within the continental sediments of the Pampiano Formation. Fidalgo (1979) assumed that they corresponded to the Last Interstadial (Sangamon) and were deposited during warmer and more humid conditions. Weiler *et al.* (1988) and González *et al.* (1988a, b) proposed two Pleistocene levels in the area, a Sangamon Interglacial and a mid-Wisconsin Interglacial but these have not been correlated with nor discussed in relation to the 'Belgranense' of Ameghino.

Age

Frenguelli (1957) considered these deposits to be a local facies of the 'Bonaerense' stage (Ameghino, 1889) and mid to late Pleistocene in age. Tricart (1973) assigned them an older age (Querandinense Stage) (Table 1). Recent authors attribute the 'Belgranense' to a late Pleistocene sea level rise but the precise age of the deposits in the study area is still uncertain. They probably

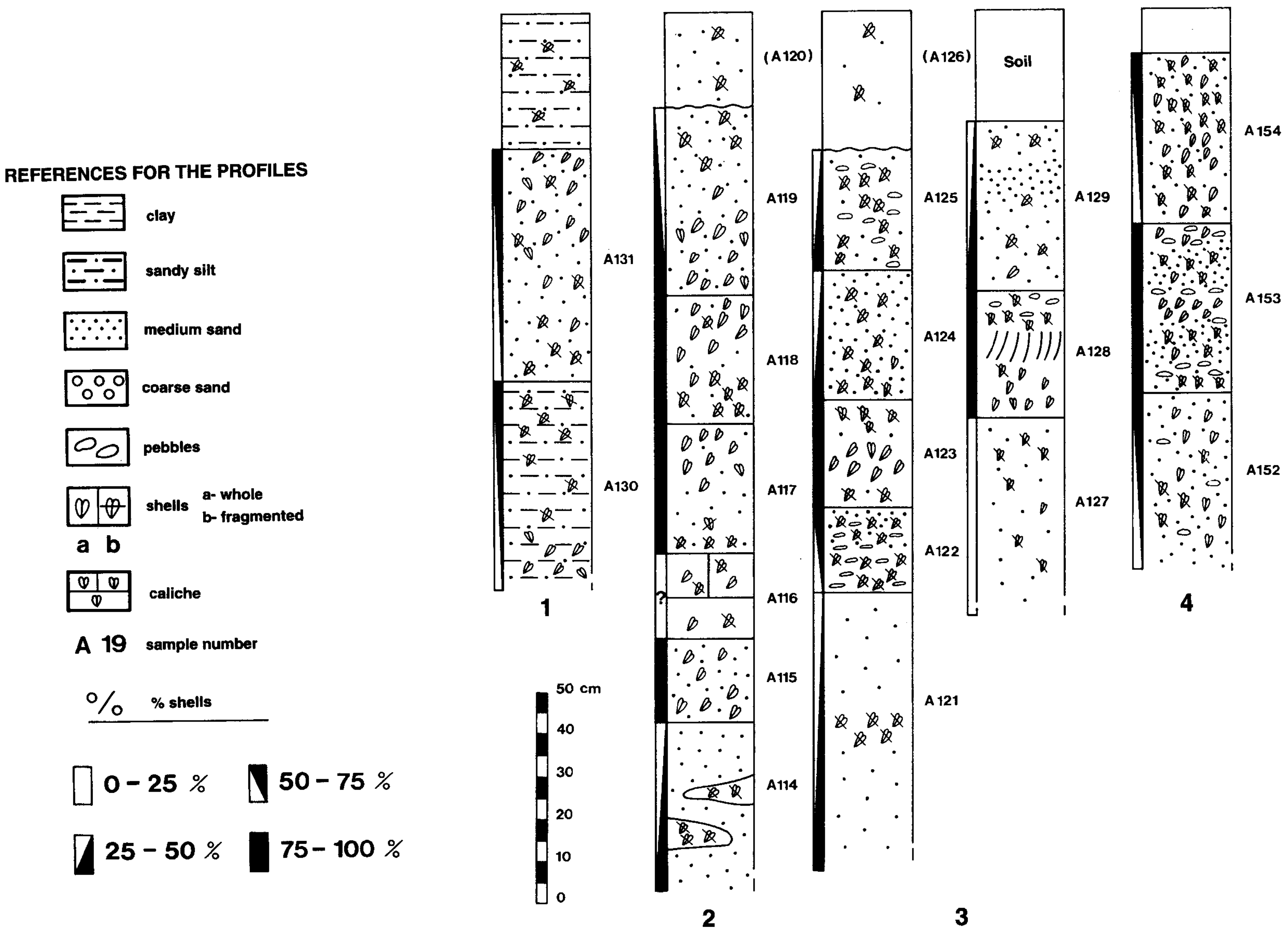


FIG. 6. Profiles and samples for palaeontologial analysis. Numbers correspond to the Holocene localities shown on Fig. 1. Berisso to Punta Piedras area. Legend refers to Figs 6, 7, 8 and 9.

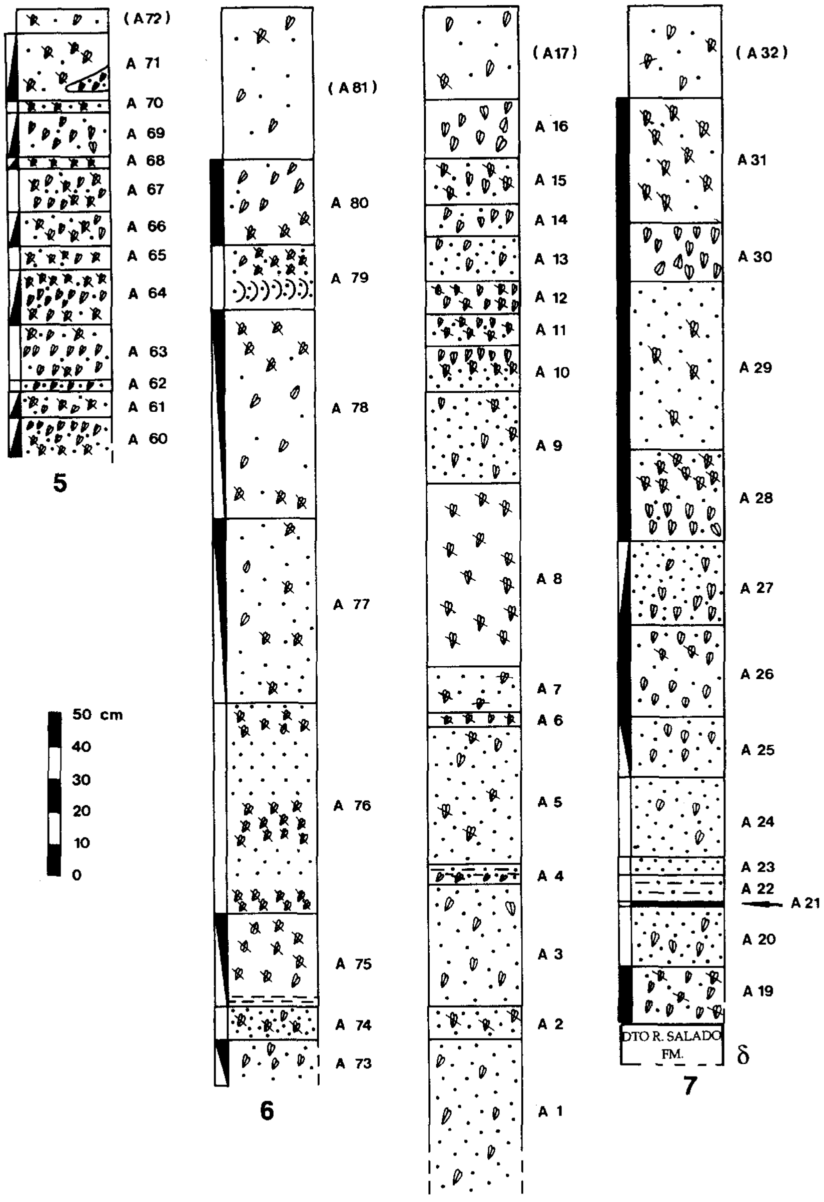


FIG. 7. Northern Samborombon Bay.

represent a higher sea-level stand (Fig. 4) during the Last Glaciation which has been recognized worldwide (Weiler *et al.*, 1988; Isla, 1989).

The published ^{14}C ages (Table 2), ca. 35,000 BP (Cortelezzi and Lermann, 1971; Cortelezzi, 1977) and 26,000–36,000 BP (González *et al.* 1988a, b), are near the limit of the range of the method and must be considered as minimum ages. The amino acid racemization method (D-alloisoleucine-L-isoleucine, using total amino acid fractions) aids in obtaining dates for more reliable comparison, the minimum ratio indicating the maximum age for the deposit.

In the Magdalena section (Figs 1 and 5, Table 3), the minimum D/L ratio on the bivalve *Tagelus plebeius* of 0.473 ± 0.556 on 7 valves with a mean age of 32,000 ^{14}C years BP, is higher than the oldest ratio obtained on the Holocene members of the same species. Similarly, the minimum D/L ratio on the bivalve *Mactra isabelleana* from Puente de Pascua (Canal 15, Fig 1) is also higher than the oldest Holocene ratio for the same species (Table 3; Aguirre *et al., submitted*).

Other late Pleistocene deposits dated in the Mar Chiquita area (Fig. 12) at > 43,000 BP and assigned to the Sangamon Interglacial (Weiler and González, 1988) may be older as the shells probably yield younger ages than they should due to cementation. This age correlates with a global low sea-level in isotope stage 2 (Clapperton, 1993).

The molluscan fauna

The studies on the Mollusca of the Bonaerensian marine Pleistocene occur as part of geological descriptions or provide only the ^{14}C ages of the molluscs. The biogenic composition (Table 4) is difficult to analyze in detail, mainly because the high degree of cementation of the shells makes their separation from the cemented matrix difficult. When treated with acid, the shells become badly corroded.

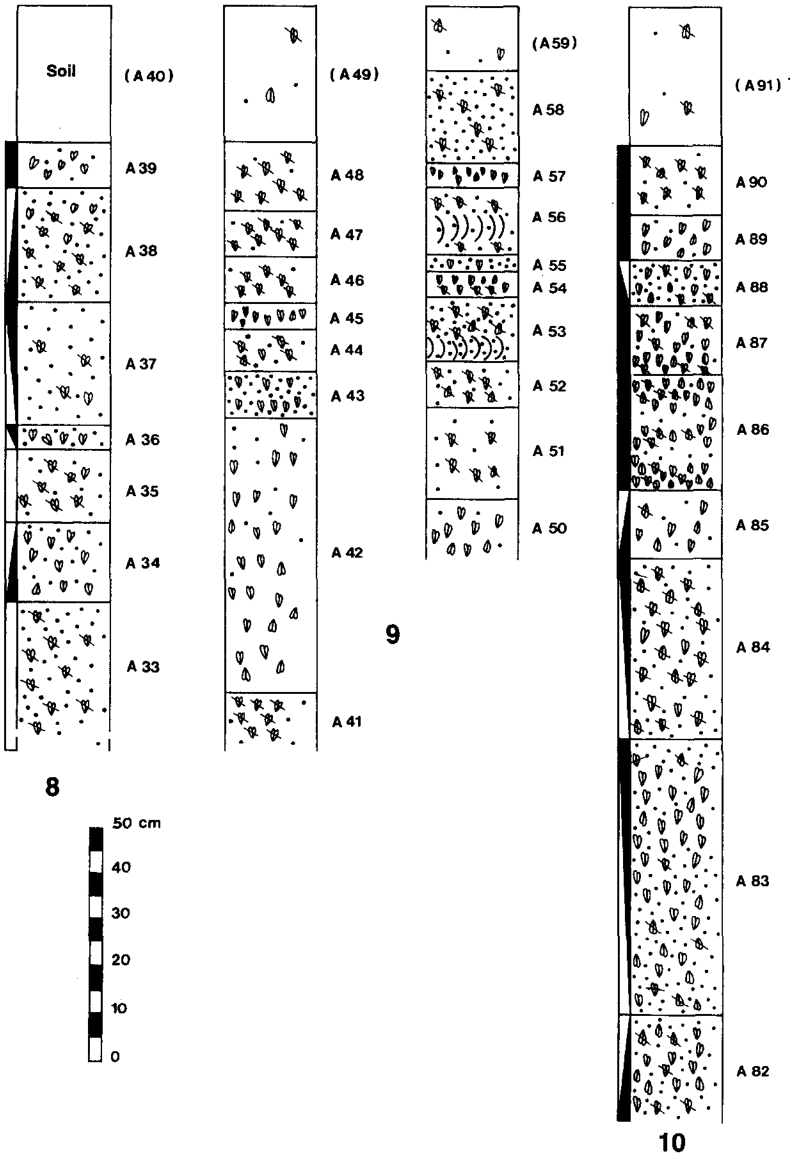


FIG. 8. Northern and Central Samborombon Bay.

Although our knowledge of this molluscan fauna is limited, in all the localities it suggests a higher (euhaline or polyheuhaline) salinity than during the mid-Holocene (mixo to poly-euhaline) for the same area. The absence of scarcity of stenohaline warm water species in comparison with the Holocene transgression suggests accumulation during an interstadial rather than an interglacial cycle.

Weiler *et al.* (1988), reported several molluscan taxa from the Sangamon Interglacial and the Mid-Wisconsinan Interstadial from the Magdalena section at less than 8 m above m.s.l. (Fig. 5): *Adelomelon brasiliana, Buccinanops cochlidium, Buccinanops deformis, Buccinanops globulossum, Conus* sp., *Crepidula* sp., *Diodora patagonica, Tegula patagonica, Thais haemastoma, Urosalpinx rushi* (Gastropoda), *Amiantis purpurata, Chlamys tehuelchus, Noetia bisulcata, Glycymeris longior, Mactra* sp., *Pitar rostrata, Ostrea* spp., *Crassostrea* sp. and *Trachycardium muricatum* (Bivalvia). Of these *Adelomelon brasiliana, Thais haemastoma* and *Noetia bisulcata* are from the Sangamon, whereas *N. bisulcata, Mactra* sp., *P. rostrata, Ostrea* sp., *Crassostrea* sp. and *A. purpurata* are from the Interstadial. On this basis, the separation of the deposits on palaeoenvironmental grounds is difficult, except for the assumption of euhaline waters and higher temperatures than in the modern nearshore, suggested by the presence of *N. bisulcata, Crassostrea* sp., *U. rushi* and *T. haemastoma.*

In the Punta Piedras area (Fig. 1) a compacted 'coquina' at some 10 m above m.s.l., containing highly cemented shells of *Adelomelon* sp. and *Mactra* sp. can be recognized and easily distinguished from the Holocene molluscs of the same region. At Puente de Pascua, at 3–4 m above m.s.l., in central Samborombon Bay (Fig. 5), *Mactra isabelleana* and *Pitar* sp. and a few other unidentified bivalve shells occur forming a highly cemented coquina (Pascua Formation). In comparison with the marine Holocene from the same area, the faunal diversity is lower, the taxa recorded are not typical of a warm interglacial period and *Littoridina australis* is absent. Conversely, this brackish water gastropod is the dominant Holocene species, suggesting that the salinity of the Pleistocene was higher than the mid-Holocene.

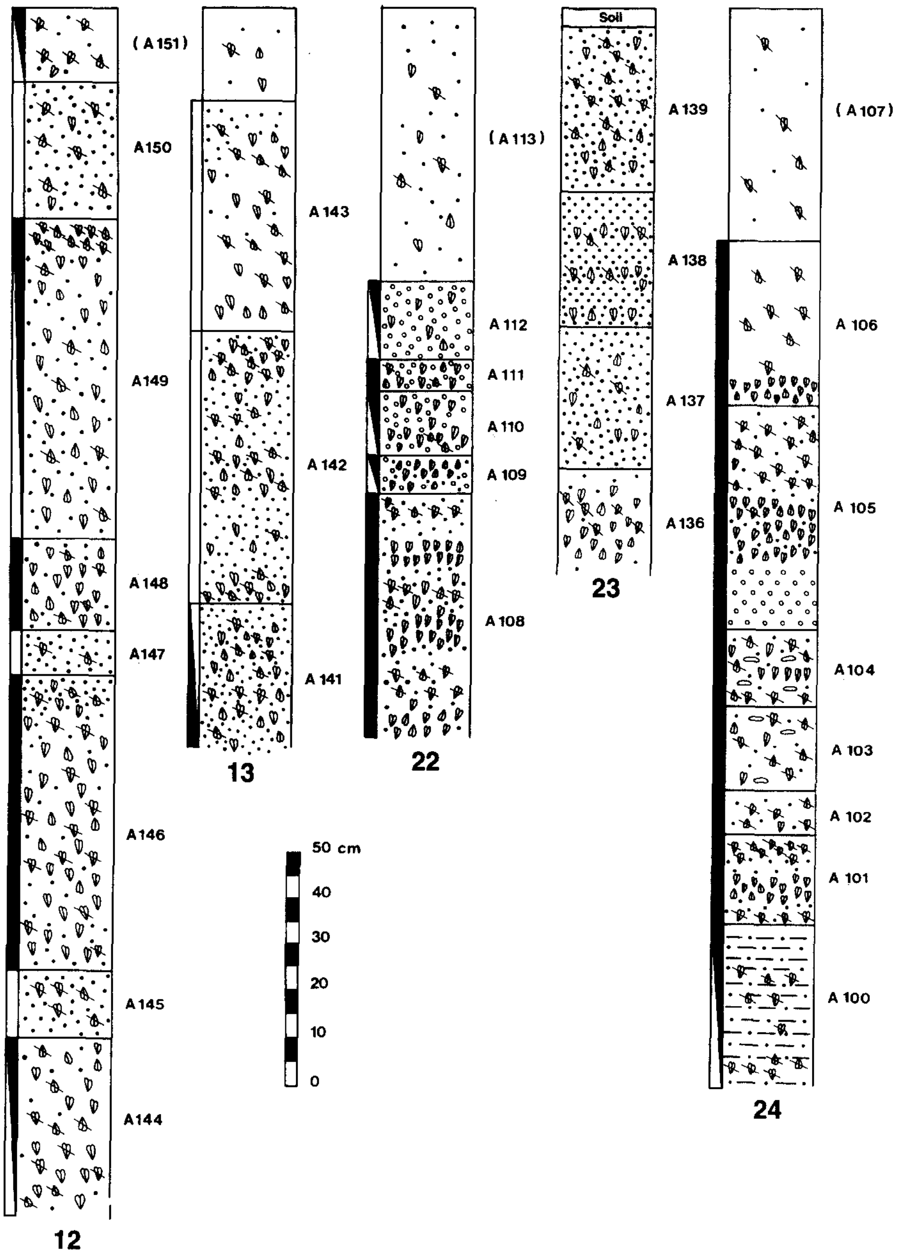


FIG. 9. Southern Samborombon Bay and Mar Chiquita areas. Modified from Aguirre (1993b).

To the south, in the area of Mar Chiquita at 5–7 m above m.s.l., Weiler and González (1988) differentiate the mid-Wisconsin Interstadial on the basis of radiocarbon ages and sparser molluscan fauna than that recovered from Magdalena. The bivalves *Glycymeris longior* and *Amiantis purpurata* and the gastropod *Adelomelon* sp. are regarded as representing the cooler interstadial period while gastropods *Buccinanops* sp., *Adelomelon* sp. and the bivalves *Pitar* sp., *A. purpurata* plus Pectinidae indet., from underlying strata, are said to be typical of the Last or Sangamon Interglacial.

In the same area, at about 4 m above m.s.l. and ca. 37,000 BP, Isla *et al.* (1986) encountered *Glycymeris longior* which suggested a more marine salinity in the area than in the subsequent Holocene ca. 5000–3000 BP.

Still further south, near Bahía Blanca (ca. 39° S) a Pleistocene sea level high of some 4.40 m above present m.s.l. and dated at 29,000 ^{14}C years BP was described by Chaar and Farinati (1988). It seems to represent the same level that Weiler and González (1988) considered to belong to the mid-Wisconsinan interstadial at Mar Chiquita although its molluscan fauna indicates somewhat warmer water: *Anomalocardia brasiliana, Crassostrea rizhophorea, Pitar rostratus* (Bivalvia), *Buccinanops deformis, Buccinanops globulossum* (Gastropoda). *C. rizophorae* and *A. brasiliana.*

Microfossils

Due to the high degree of cementation of the sediments, no microfaunal analysis has been undertaken for the 'Belgranense'.

Vertebrates

Although no Pleistocene marine vertebrates have been studied, the terrestrial vertebrate faunas from the so called 'Pampiano' continental sediments (Pliocene to late

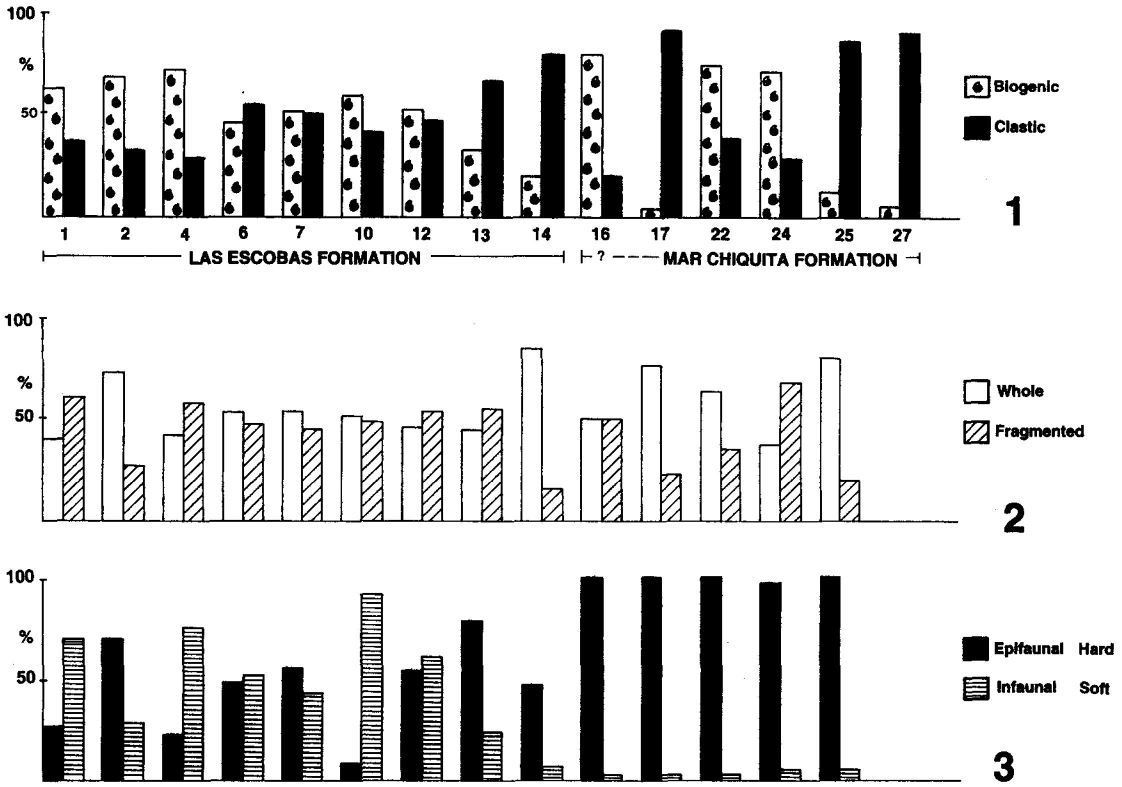


FIG. 10. Percentage components of the mid-Holocene localities studied quantitatively. (1) Biogenic/clastic content; (2) whole/fragmented shells; (3) life habit of the predominant taxa (and their substrate preference) (modified from Aguirre, 1993b).

Pleistocene), on which most of the marine units rest (Table 1), are well known from the classical works of Darwin (1846, 1876), Ameghino (1906, 1908) and Kraglievich (1952). More recently they have been studied in detail by Pascual *et al.* (1965), Patterson and Pascual (1968), Simpson (1980) and Tonni *et al.* (1992). The Pleistocene vertebrate faunas found in the study area belong to the early and mid Pleistocene 'Ensenadense' (= Ensenadan) or to the late Pleistocene 'Lujanense' (= Lujanian) mammal ages which correspond to the 'pampian' sediments of authors (Pampiano Formation) (Fig. 2, Table 2) (Tonni and Fidalgo, 1978; Tambussi *et al.*, 1993).

During the Pleistocene, the Bonaerensian pampas were inhabited by numerous large mammals, most of which became extinct by the end of the period. They represent both indigenous and immigrant groups from North America, which first appeared in the Pliocene and early Pleistocene 'Montehermosean' and 'Uquian' mammal ages. Among the most remarkable and interesting taxa are the gigantic glyptodonts, mastodons and megatherids (edentates of the genus *Megatherium*, Glyptodontia), the 'armadillos' (*Eutatus, Chlamydophorus*, Dasypoda), peccaries, numerous deer, several llamas (Artiodactyla), and hoofed animals (*Toxodon, Typotherium, Macrauchenia*) as well as large carnivores (great immigrant sabre-tooth *Smilodon*). The following major mammal groups have been recorded in the pampean region (B. Scott, 1940; Tonni, *pers. commun.* 1984):

Xenarthrans

Dasypodidae: *Euphractus, Dasypus, Tolypeutes;* Megatheriidae: *Megatherium;* Glyptodontidae: Glyptodon, Doedicurus; Mylodontidae: Scelidotherium: Myodon.

Caviomorph Rodents

Dynomidae: *Dynomys*; Echimyidae: *Cercomys, Myocastor;* Caviidae: *Microcavia*; Chinchillidae: *Lagostomus.*

Ungulates

Machraucheniidae: *Maccrauchenia*

Notoungulates

Toxodontidae: *Toxodon.*

Discussion

The amino acid ratios together with the radiocarbon dates (26–36 ka BP) for the marine deposits of Magdalena and Puente de Pascua indicate a late Pleistocene age and the fauna suggests interstadial rather than interglacial conditions, probably the mid-Wisconsinan interstadial. Unfortunately, the available data on the Stage 3 interstadial in South America is very poor. A review by Isla (1989) provides evidence for a mid-Wisconsinan interstadial ca. 30–40/50 ka BP, while Rabassa and Clapperton (1990) placed an interstadial at ca. 60–30 ka BP Clapperton (1993) established that the main glacier advanced in South America was in progress soon after 34 ka BP and had culminated by ca. 27 ka BP. In addition, unpublished data from different sources (pollen, northern Andes; peat, Ecuador; palaeolakes, Bolivia; glaciers, Chile; shells incorporated in tills, Magellan Strait and Alexander Island in Antarctica; Clapperton, *written commun.* 1994, *submitted*

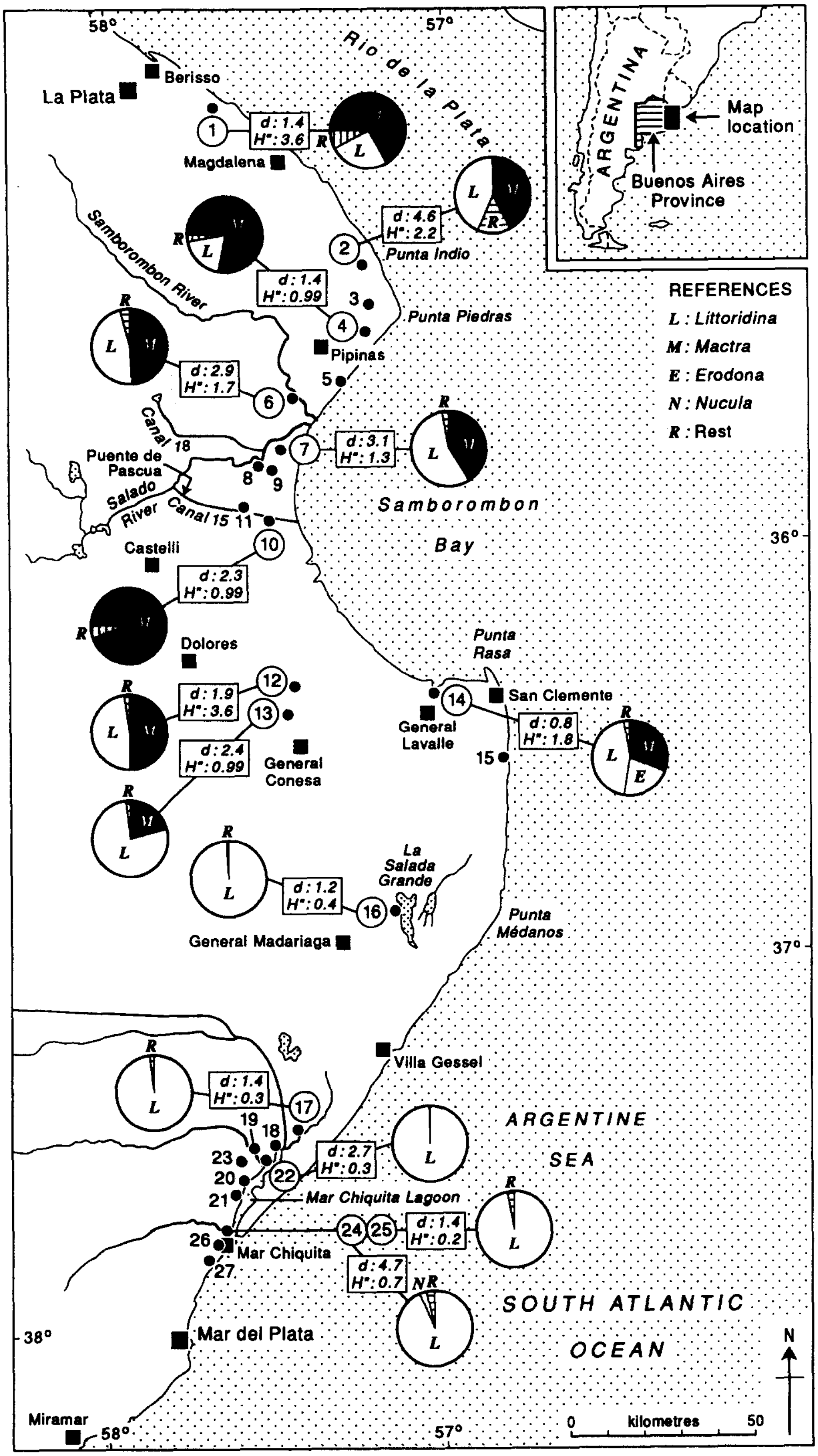


FIG. 11. Relative abundance of the most representative molluscan genera (bivalves and gastropods), diversity (H") and species richness (d) for the localities quantitatively studied (shown within a circle) (modified from Aguirre, 1991).

TABLE 2. Radiometric ages of the late Quaternary deposits from the study area and from other neighbouring deposits along eastern South America (Brazil, Uruguay; Bahía Blanca south to Tierra del Fuego in Argentina). For the area of this study the 'Belgranense' (B) corresponds to the late Pleistocene beach deposits; the 'Querandinense' (Q) includes marshy deposits located in the Pleistocene–Holocene boundary (Destacamento Río Salado Fm., i.e. loc. 7, Fig. 7) and the 'Platense' (P) corresponds to the Holocene littoral beach ridges (Cerro de la Gloria Member of the Las Escobas Fm.) represented by most of the localities studied (Figs 1, 5), except loc. 11 in central Samborombon Bay (+ = Canal 18 Member of Las Escobas Fm., coastal lagoon)

STAGES	BRAZIL (ca. 32 S)	URUGUAY	A R G E N T I N A																		
			E.RIOS (ca. 33.5 S)	ISLA M. GARCIA (ca. 34 S)	LA PLATA	MAGDALENA	P. INDIO	P. PIEDRAS	PIPINAS	SAMBOROMBON BAY (+ 2.5-5)			SAN CLEMENTE (+3)	MAR CHIQUITA AREA (+2-4)	MAR DEL PLATA	P.QUEQUEN (+2.5)	BAHIA BLANCA (+5-10)	BAHIA SAN BLAS	COLORADO DELTA	PATAGONIA	T.DEL FUEGO (+2.5-14)
										NORTH	CENTER	SOUTH									
PLATENSE	(+5) 5,100 7,000 (+2) 2,500 2,700 3,600 4,000 5,150 7,100 a	(+4) 2,450 5,420 5,980 b	(+5) 5,610;6,440 c	(+5.2) 5,730;5,800 c	(+2.5) 2,040; 2,300; 2,810 2,990; 3,530 5,140; 6,160 b,d		3,100 +5-6 4,460-7,600	f b		M 3,762 4,067 [7890] Eu 4,730 h	3,650;5,630 5,770 3,050 4,920;5,934; 6,056 M 3,320;4,100 M 4,500-4,800 M 3150-4,440 A 3,150-6,850 2,540-3,000 T (***) 6,150; 6,459; 6,764 h,i,j,k, l,m	M 4,850;4,960 5,580;6,890 m	1,610-5,810 m	T (+2) 1,340;2,700; 2,800 (+2-4) 2,700;4,000 M 3,110;3,620; 3,850 ~ 3,000;3,200 3,370 3,400 4,000 5,000 (max.) n,b,o,p		7,500 (max.) T 5,340 (top) T 6,230; 7,130; 7,140; 7,640 (bottom) q,r	B (+8-10) 4,615 (+10) 5,990 # 1,000-7,500 c,s,t	(+3) 2,170 -3,450 I J (+7) 4,100- 5,370 v	(+5) 6,000 c	SC 1,550-6,420 BB 2,030;2880 C 3,860-7,520 CV 1,330-5,720 PL 750-3,310 SAO ca.2,000 (+8-10) BB 5,820-8,950 (+8-12) <6,000 r,v,w,z	1,310- 3,820 (+2.5) 1,400 (+3.10) 4,425 (+3.55) 4,600 (+3.95) 7,518 (+4.30) 3,860 (+5) 4,790 4,440 (+8) 5,160 (+8.40) 5,920 (+8.5) 5,430 (+10) 5,460 w,z
Q											7,030 h				11,010 (xxx)						
BELGRANENSE			(+5-7) 26,600;30,800; 32,700;33,000; 35,400 c	(+9.8; 6.8) 32,200;38,500 b	(+0.50) 35,700 (+3.40) 34,000 b	35,000 (+3.16) > 35,000 35,900 (+1.10) 35,900 c,d,e		35,000 d	(+10) 30,000 30,000- 35,000 b,g					~ ca.24,900 G 37,000 * >43,000 c,e	G (+10) 30,500 c		(+12.5-14.5) 25,700 35,500 An (+4.40) 29,580 c,u	(+9-10) 28,400 29,120 v v,w,x,y	(+7) 28,700 30,000 c	SC 25,000-39,000 BB 31,000-37,000 C 32,000-39,000 CV 38,700 PL 20,000-42,000 (+7-8) 29,000-41,000 34,000-41,000 SAO 66,800-70,300 SAO 169,000;208,000; 218,000; 230,000 (+10) SAO 83,200-111,000 BB 41,800-151,000	31,900 32,000 (+20) >43,000 w

REFERENCES:
a=Martin & Suguio, 1992; Martin *et al.*, 1993 (references therein); b=Cortelezzi & Lerman, 1971; c=González *et al.*, 1986; d=Cortelezzi, 1977; e=Weiler *et al.*, 1988; f=Gómez *et al.*, 1985; g =Isla 1989; h= Fidalgo et al., 1981; i=Fidalgo, 1979; j=Figini *et al.*, 1984; k=Gómez *et al.*, 1988; l=Figini *et al.*, 1990; m=Codignotto & Aguirre, 1993; n=Schnack *et al.*, 1982; o=Weiler & González, 1988; p=Violante, 1988; q=Fasano *et al.*, 1987; r=Isla *et al.*, 1986; s= Aliotta & Farinati, 1990; t= Farinati, 1985b; u=Chaar & Farinati, 1988; v=Rutter *et al.*, 1990 (references therein); w=Codignotto, 1983; x=Isla, 1984; y=Rutter *et al.*, 1989; z=Gordillo *et al.*, 1992, 1993.

References: (+5) = height (in m above present m.s.l.); [ ] = probably unreliable date. Localities: * = Laguna de Sotelo; # = Punta Médanos; V = General Madariaga; in Patagonia: IJ = Isla Jabalí; SAO = San Antonio Oeste; BB = Bahía Bustamante; C = Camarones; CV = Caleta Valdés; PL = Puerto Lobos; SC = Santa Cruz; Bivalve taxa dated: M = *Mactra isabelleana*; T = *Tagelus plebeius*; An = *Anomalocardia brasiliana*; G = *Glycymeris longior*; C = *Crassostrea* sp.; # = different molluscan taxa; Eu = *Eubalaena* sp. (colagene).

Source of information: Brazil, Martin *et al.* (1993, and references therein); Uruguay, references in Cortelezzi and Lerman (1971); Argentina, Cortelezzi and 1971 and Cortelezzi, 1977 (compilation of dates obtained in the following laboratories; La Jolla, California; Groningen, Holland; Instituto Venezolano de Investigaciones Científicas; Lamont Geochemical Laboratory); Fidalgo (1979), Fidalgo *et al.* (1981), Figini *et al.* (1984, 1990), Gómez *et al.* (1988), Chaar and Farinati (1988) (LATYR Laboratory, University of La Plata); Fasano *et al.* (1982), González *et al.* (1986, 1988), Weiler *et al.*, 1988; Weiler and González (1988), Aliotta and Farinati (1990), Codignotto and Aguirre (1993) (Ingeis Laboratory, University of Buenos Aires); Fasano *et al.* (1987) (Groningen Laboratory). Additional data from Isla (1989) and Isla *et al.* (1986), for Patagonia ESR and U/Th series were obtained by Rutter *et al.* (1990) and the ^{14}C age for the 'Querandinense' off Mar del Plata corresponds to the continental shelf (Richards and Craig, 1963).

TABLE 3. D/L ratios obtained on D-alloisoleucine–L-isoleucine of bivalve shells from the Quaternary marine deposits along the study area. All in free amounts (complete list of ages and source of information in Aguirre *et al.*, *submitted*). Samples location shown in Figs 1, 5 and 6–9

D/L RATIOS / DEPOSITS	SAM-PLES	*Mactra isabelleana*		*Corbula patagonica*		*Tagelus plebeius*		*Noetia bisulcata*		*Macoma uruguayensis*	
		Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean
HOLOCENE											
Punta Indio	A201	0.11	0.128	0 .179	0.197	0.123	0.153	0.123	0.149		
	A99							0.089	0.121		
Punta Piedras	A192	0.08	0.098	0.109	0.14						
Samborombon Bay	WA-6	0.048	0.082				0.075			0.068	0.097
	WA-8					0.053					
Mar Chiquita	A101	0.053	0.08			0.101	0.114				
PLEISTOCENE											
Magdalena	AC-0911					0.473	0.556				
Puente de Pascua	A210	0.308	0.385								

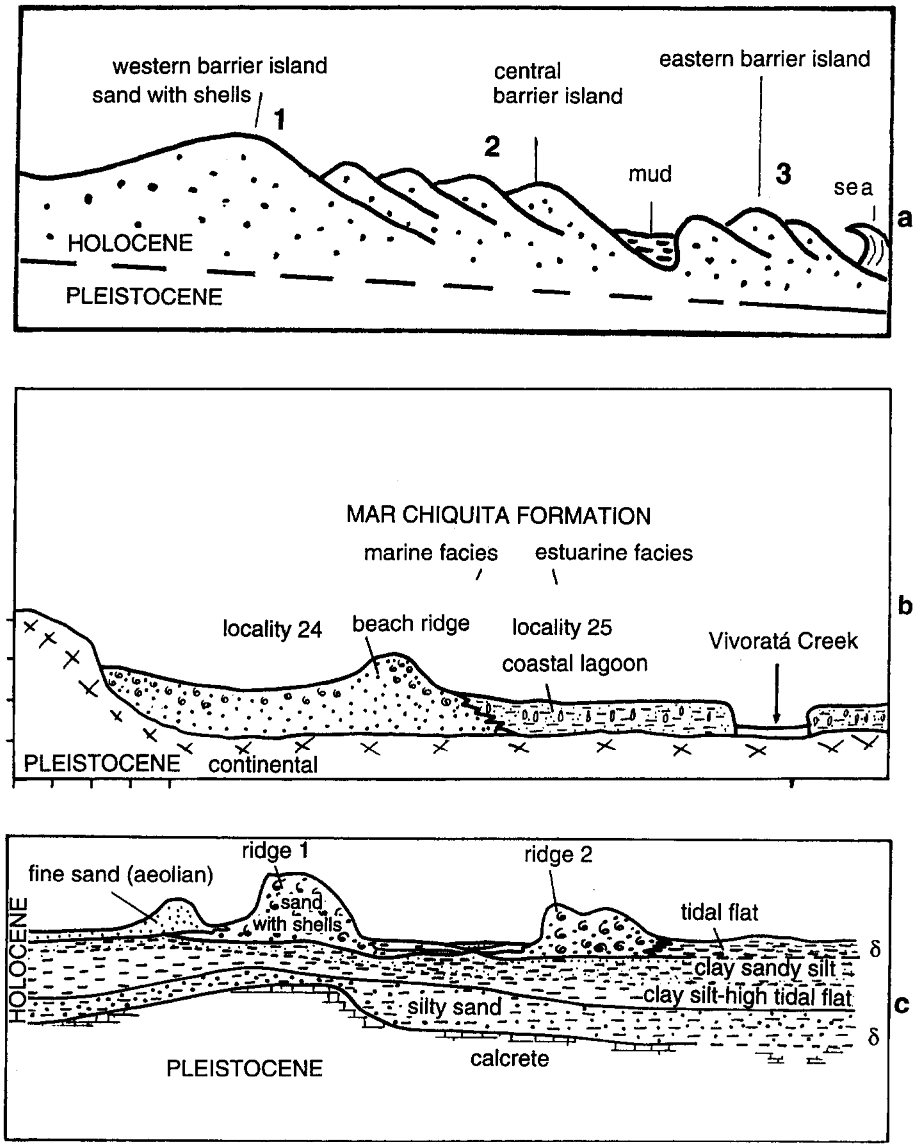


FIG. 12. Stratigraphical cross-sections of the Holocene marine deposits (sand-shell ridges) from Samborombon Bay (a), Mar Chiquita (b) and Bahía Blanca (c) (after Codignotto and Aguirre, 1993; Schnack *et al.*, 1982; Aliotta and Farinati, 1990).

manuscript) all support either warmer conditions and deglaciation processes or a higher sea level during the interval 34–27 ka.

On the other hand, neotectonics and subsidence during the accumulation of the marine late Pleistocene deposits cannot be ruled out in our study area. The poor chronological control, the oxygen isotope record and evidence from glacier advances in South America (see review by Clapperton, 1993 and references therein) tend to militate against a higher than present sea level between 26 and 36 ka BP. However, the marine oxygen isotope record depends on changes both in ice volume and in ocean temperature, which are two independent signals, and should not be taken as an exact quantitative estimation of the ice volume (see Broecker and Denton, 1990, p. 305). Further analyses and dating, especially with AMS, are required to confirm whether these deposits correspond to an interstadial at ca. 34–27 ka or an interstadial episode during isotope stage 5.

'Querandinense' Stage

Marine and mixed sediments originally named the 'Querandino' stage (Doering, 1892) were originally placed in the Pleistocene (Table 1). They are found in several localities, below or at present sea level, along the Bonaerensian coastal area from San Nicolas and Belgrano in northern Buenos Aires city south to Bahía San Blas, ca. 40° S in southernmost Buenos Aires Province. Ameghino (1889) used this name for sands and clays with marine shells near La Plata which he placed in the mid Pleistocene.

Frenguelli (1957) names the 'Querandinense' substage for transgressive sediments found in the estuary of the Río de La Plata and formed when sea level began to rise during the latest Pleistocene and earliest Holocene. Fidalgo (1979) named these coastal lagoons and marsh deposits the Destacamento Río Salado Formation, of late Pleistocene to early Holocene age, and partially equiva-

TABLE 4a. Molluscan composition of the Quaternary (late Pleistocene and Holocene) marine deposits from Buenos Aires Province coastal area: 4a, bivalves

TAXA (Bivalvia) / LOCALITIES	ARGENTINA: BEACH RIDGES (P) Bs. As. Prov.: P.I.-P. Piedras	Samb. Bay	Mar Chiquita	Bahia Blanca	Patagonia	T. del Fuego	(COASTAL LAGOON) Q	(B) Beach deposits Magdalena	P.I.-P. Piedras	P. de Pascua	Lag. de Sotelo	Mar del Plata	Bahia Blanca
EPOCH	HOLOCENE							PLEIST					
Nucula nucleus	x	x	x										
Nucula obliqua	x	x	x		x								
Nucula uruguayensis													
Nuculana whitensis				x									
Adrana electa				x									
Adrana patagonica				x									
Arca transversa													
Anadara brasiliana													
Anadara ovalis													
Anadara notabilis													
Anadara sp.													
Noetia bisulcata	x							x					
Glycymeris longior		x			x			x			x		
Glycymeris sp.					x								
Mytilus edulis	x	x	x		x	x							
Mytilus sp.													
Brachidontes rodriguezi	x	x	x										
Brachidontes purpuratus					x	x							
Brachidontes sp.													
Aulacomya ater						x							
Aulacomya magallanica					x	x							
Musculur viator				x		x							
Plicatula gibbosa													
Chlamys tehuelchus				x				x					
Pecten sp.					x								
Ostrea equestris	x	x	x										
Ostrea cf. equestris	x	x	x		x								
Ostrea sp.					x			x					
Crassostrea sp.													x
Carditamera guppyi	x	x											
Carditamera sp.					x								
Cardita sp.					x								
Crassinella maldonadoensis				x									
Crassinella cf. guadalupensis													
Lucina sp.													
Diplodonta patagonica	x	x	x		x								
Diplodonta semiaspera				x									
Diplodonta vilardeboana					x								
Codakia aff. orbiculata													
Codakia sp.					x								
Divaricella sp.													
Mactra isabelleana	x	x	x		x		x	x	x	x			
Mactra patagonica	x	x			x								
Mactra sp.	x	x						x					
Raeta plicatella		x	x										
Mulinia lateralis					x	x							
Mulinia edulis						x							
Darina solenoides				x									
Mesodesma mactroides				x									
Solen tehuelchus				x									
Tellina gibber				x									
Tellina sp.					x								
Strigilla camaria				x									
Strigilla cf. rombergii													
Strigilla sp.													
Macoma uruguayensis		x	x										
Abra aequalis		x	x										
Abra uruguayensis													
Tagelus plebeius		x	x	x									
Donax hanleyanus				x									
Semele proficua				x									
Semele purpurascens				x									
Semele bellastriata													
Semele sp.					x								
Cardium del;icatulum													
Trachycardium muricatum				x				x					
Venericardia tridentata													
Tivela isabelleana				x									
Tivella sp.					x								
Chione paphia													
Chione sp.					x								
Pitar rostratus		x	x	x	x			x		x	x		x
Amiantis purpurata				x				x			x		
Gouldia camachoi				x									
Gouldia cerina													
Protothaca antiqua					x	x							
Samarangia exhalbida					x	x							
Clausinella gayi					x								
Anomalocardia brasiliana	x	x											x
Petricola lapicida		x	x	x									
Petricola pholadiformis		x		x									
Petricola sp.													
Sphenia hatcheri				x									
Corbula patagonica		x	x	x	x								
Corbula caribaea													
Corbula lyoni													
Corbula nasuta													
Corbula iheringiana													
Corbula sp.													
Erodona mactroides		x							x				
Cyrtopleura lanceolata		x	x	x									
Barnea lamellosa				x									
Nettastomella darwini				x									
Lyonsia alvarezii			x										
Entodesma patagonicum		x	x	x									
Periploma ovatum				x									
Angulus gibber					x								
Thracia similis				x									
Bushia rushi				x	x								
Panopea abreviata				x		x							
Pleuromeris sarmantini													
Hiatella solida						x							

TABLE 4b. Gastropods. P = Platense; Q = Querandinense; B = Belgranense

TAXA (Gastropoda) LOCALITIES	ARGENTINA BEACH RIDGES (P)						COASTAL LAGOON (Q)	(B)					
	Bs. Aires Prov.												
	P. I-P. Piedras	Samb. Bay	Mar Chiquita	Bahia Blanca	Patagonia	T. del Fuego		Magdalena	P. I-P. Piedras	P. de Pascua	Lag. de Sotelo	Mar del Plata	Bahia Blanca
Calyptraea pileolus						x							
Calyptraea dilatata						x							
Patinigera deaurata					x	x							
Patinigera magallanica					x								
Fissurella picta					x								
Fissurella oriens					x								
Fissurella radiosa					x								
Diodora patagonica	x		x		x			x					
Puncturella conica				x									
Lucapinella henseli				x									
Tegula patagonica	x	x	x					x					
Tegula atra					x								
Photinula caerulescens					x								
Nucella calcar					x								
Calliostoma coppingeri				x									
Calliostoma carcellesi				x									
Calliostoma nordenskjoldi				x									
Littoridina australis		x	x				x						
Littoridina parchappii					x								
Littoridina sp.			x										
Crepidula dilatata	x	x			x								
Crepidula aculeata	x	x	x										
Crepidula protea	x		x										
Crepidula cf. onyx	x		x										
Natica isabelleana	x	x						x					
Natica magellanica					x								
Falsilunatia limbata						x							
Macromphalina argentina				x									
Vitrinella agulhasensis				x									
Cochliolepis surensis				x									
Teinostoma maldonadoensis				x									
Caecum achironum				x									
Caecum antillarum				x									
Ataxocerithium pullum				x									
Epitonium georgettinum	x	x	x										
Epitonium tenuistriatum				x									
Trophon geversianus				x	x	x							
Trophon muriciformis						x							
Trophon varians					x								
Trophon deccolor					x								
Trophon necocheanus					x								
Triphora nigrocincta	x												
Urosalpinx cala	x	x	x	x									
Urosalpinx rushi	x							x					
Thais haemastoma					x			x					
Acanthina imbricata						x							
Paraeuthria plumbea						x							
Euthria cerealis					x								
Eutria rosea					x								
Euthria meridionalis					x								
Zidona angulata	x	x		x									
Adelomelon brasiliana		x						x	x		x		
Adelomelon ancilla				x	x	x							
Adelomelon beckii				x									
Adelomelon sp.													
Odontocymbiola magallanica					x								
Olivancillaria brasiliana	x	x		x									
Olivancillaria auricularia		x			x								
Olivancillaria carcellesi	x	x											x
Olivancillaria uretai				x									x
Olivancillaria deshayesiana													
Marginella martini				x									
Margarella violacea						x							
Olivella tehuelchana		x			x								
Olivella puelchana	x	x											
Buccinanops sp.	x	x	x										
Buccinanops gradatum	x	x											
Buccinanops lamarckii	x	x						x					
Buccinanops deformis		x						x					x
Buccinanops globulosum	x	x			x			x			x		x
Conus sp.								x					
Dorsanum moniliferum	x		x										
Anachis avara		x											
Anachis paessleri				x									
Anachis isabellei				x									
Anachis obesa	x		x										
Aesopus metcalfei				x									
Drillia patagonica	x		x										
Mangelia cf. purissima			x										
Mangelia sp.		x	x										
Eulimella argentina				x									
Turbonilla uruguayensis	x	x	x										
Turbonilla fasciata	x	x	x										
Turbonilla americana		x	x										
Turbonilla smithi				x									
Turbonilla rushi				x									
Turbonilla interrupta													
Turbonilla madrynensis				x									
Scala orbigny					x								
Scala magellanica					x								
Cochliolepis surensis				x									
Teinostoma maldonadoensis				x									
Cylichna crispula	x	x	x										
Actaeocina candel	x		x	x									
Siphonaria lessoni			x		x	x							
Lathyrus frenguelli					x								
Nucella calcar					x								
EPOCH	HOLOCENE							PLEIST					

TABLE 5a. Microfossils from the late Pleistocene and Holocene marine deposits along the Buenos Aires Province coastal area: 4a, ostracods; 4b, forams (samples recorded along Samborombon Bay are under current more detailed study)

OSTRACODS	F W						FW-B	B					B M		MB			M															INFERRED SALINITY
SAMPLES	*Cypridopsis sp.*	*Ilyocypris sp.*	*? Candona sp.*	*Limnocythere sp.*	*Cypridopsis assimilis*	*Chlamydotheca sp.*	*Pampacythere solum*	*Cyprideis multidentata*	*Cyprideis salebrosa*	*Perisocytheridea sp.*	*Leptocythere sp.*	*Cytherura sp.*	*Callistocythere nucleoperiscum*	*Callistocythere rioplatensis*	*Loxocythere variasculpta*	*Neocytherideis sp*	*Cushmanidea n. sp.*	*Cytheretta sp.*	*Protocytheretta sp.*	*Papillosacythere parallela*	*Oculocytheropteron macropunctatum*	*Procythereis igandersoni*	*Procythereis sp.*	*Loxoconcha sp.*	*Loxoconcha bullata*	*Loxoreticulatum diktyotos*	*Meridionalicythere sp.*	*Paracondona sp.*	*Neocaudites sp.*	*Paradoxostoma sp.*	*Pellucistoma sp.*	*Other genera*	
BUENOS AIRES PROVINCE																																	MARINE BRACKISH
Punta Indio																																	
A95													H,M 4								J A-				A-3		J						
Punta Piedras																																	
A97									2A-1				H 2	H 1				X															
A99													A3					3A,M H			1				A1	1							
A199													J, A-5								J, 2A												
Samborombon Bay																																	B R A C K I S H
N																																	
WA1																		1A															
WA-2													X												1 J								
WA-3																																	
WA-9								>A,A-1,A-2,A-3																									
C																																	
WA-4																		1 H,RV															
WA-5			1 sp		x				2sp																								
WA-6																					1 sp												
205								>A, A-1	L; >A; A-1																			A, J					
206								>A, A-1	>A, A-1																								
208									X																								
WA-7																					1 sp									1 sp			
WA-8							2A	20 sp;Ad - A-5	A; A-5				2	1	1	1 sp	X	J, A-2	X	1A, 1J	2A, 2J	1		X					2 J, 2Ad		X		
Canal 15 (B)									A-2, A-3	2A			2A	1A							1a								3 J				
Samborombon Bay (A)								1AM, 1AH	A, J; 2A-5												2A-1;fr.		A-1										
Samborombon Bay (B)																																	
Dto. Rio Salado		X		X 6 spp	X	X	X	abund.	>A-1 -6																								BRACKISH TO FRESHWATER
Mar Chiquita (Fasano et al., 1983				X			X		X		X	X																					BRACKISH
Bahia Blanca (González et al., 1983)		X		X	X						X	X	X			X	X															X	BRACKISH

REFERENCES:

N, C : northern and central Samborombon Bay coastal area

* : Pleistocene-Holocene boundary (coastal lagoon facies)

"Other genera":

Caudites, Cytherella, Hemicytherura, Hemanites, Mutilus, Krithe, Microcytherura, Neocypridies, Australimoosella, Pterygocythereis, Pellucistoma, Semicytherura, Xestoleveris

In Bahía Blanca the ostracods were determined only to the genus level; in Mar Chiquita the species indicated are only the most common ones.

SALINITY: FW= freshwater; B= brackish; M= marine. All the taxa are living in lagoons or in the adjacent nearshore.

TABLE 5b. Microfossils from the late Pleistocene and Holocene marine deposits along the Buenos Aires Province coastal area: 4a, ostracods; 4b, forams (samples recorded along Samborombon Bay are under current more detailed study)

FORAMS / **LOCALITIES**	*Bolivina striatula*	*Bolivina variabilis*	*Bolivina translucens*	*Bolivina sp.*	*Buccella peruviana*	*Bulivina elongata*	*Buliminella elegantissima*	*Elphidium articulatum*	*Elphidium discoidale*	*Elphidium gunteri*	*Elphidium cf. gunteri*	*Elphidium excavatum*	*Florideus pauperatus*	*Globulina australis*	*Guttulina lactea*	*Guttulina plancti*	*Guttulina problema*	*Lagena laevis*	*Lagena sp.*	*Oolina caudigera*	*Oolina globosa*	*Quinqueloculina patagonica*	*Streblus parkinsoniana*	*Rotalia beccari*	*Discorbis williamsoni*
BUENOS AIRES PROVINCE (Holocene)																									
Mar Chiquita				x	x				x													x		x	x
Bahía Blanca	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		

REFERENCES:
Mar Chiquita: Fasano et al., 1983
Bahia Blanca: Gonzalez et al., 1983

lent to the 'Querandinense' of Frenguelli (Fig. 4). Fidalgo's climatic reconstruction required their formation in very cool and dry conditions, immediately after the Last Glaciation (Table 6).

Tricart (1973) considered the 'Querandinense', deposits at some 10 m above m.s.l. which were formed by a marine transgression, accumulating as littoral beach ridges to which he assigned a Lower Pleistocene age. On the basis of the morphological and sedimentological characteristics and their altitude, it is almost certain that the 'Querandinense' deposits of Tricart (1973) correspond to the 'Belgranense' of Ameghino (1889), not of Frenguelli (1957) (see Fidalgo, 1979).

Age

A radiocarbon date ca. 7030 BP was reported by Fidalgo *et al.* (1981) for locality 7 in Samborombon Bay (Figs 1 and 7). This age correlates with the climatic optimum (Hypsithermal) of the Holocene but conversely, the available palaeoecological data do not fit with this event (see below). In the continental shelf off Mar del Plata, these deposits, sampled at 115 m by the 'Vema' expedition along the southwestern South Atlantic (Richards and Craig, 1963), were radiocarbon dated at 11,000 ± 150 BP, which correlates with the Lateglacial climatic changes during the termination of the Pleistocene (Heusser and Rabassa, 1987; Mott, 1994; Ingolfsson and Norddahl, 1994; Walker *et al.*, 1994).

Faunal composition

The 'Querandinense' deposits (Figs 4 and 7) are characterized by a high proportion of clastics (clays and silts) and a low faunal diversity and abundance. Only a few whole, very thin shells of the bivalve *Mactra isabelleana*, and a few specimens of the gastropod *L. australis* were recovered. The presence of these molluscs, together with the absence of warm water marine species and others typical of fine-grained substrates, such as occur abundantly in subsequently Holocene deposits, suggest quite different environments for the Querandinian and Platensian deposits. The former is certainly cooler.

The microfauna of ostracods (Table 5) and forams recovered from this unit supports the molluscan evidence. The ostracods indicate the presence of freshwater to brackish environments in colder waters than at present in the adjacent nearshore and the forams are also indicative of mixed waters but the thermal requirements of the extant are still under investigation. In addition, palynological evidence from sediments assigned to the Destacamento Río Salado Fm. near Castelli (Fig. 1) indicate that they correspond to a halophytic vegetation in a dry, cold and windy climate. Recent zooarchaeological evidence from Patagonian and Bonaerensian sites (Salemme and Miotti, 1987) also revealed a climatic deterioration near the Pleistocene–Holocene boundary as causing the extinction of Pleistocene megamammals.

In many respects this resembles the Younger Dryas chronozone recognized in the northern hemisphere at the Pleistocene–Holocene boundary. However, in South America the palaeoenvironmental and climatic changes that occurred during the termination of the Pleistocene are highly controversial. The occurrence of the Younger Dryas cool event at ca. 10,800–10,000 ^{14}C years BP has been recognized or dismissed mostly on the basis of pollen, beetle assemblages or glaciological evidence and recently on foraminiferal data (Heusser *et al.*, 1981; Heusser and Rabassa, 1987; Markgraf, 1989; Boltovskoy, 1990; Ashworth and Hoganson, 1993) whereas no marine molluscan assemblages have as yet been considered.

The only radiocarbon date for Samborombon Bay is at

TABLE 6. Model for the late Quaternary cliamatic oscillations in the area of study. Source of information in Rabassa (1987), Rabassa and Clapperton (1990), Tonni and Fidalgo (1978), Fidalgo (1979), González *et al.* (1988), Iriondo and García (193), Aguirre (1993a), Clapperton and Sudgen (1988), Fernández and Romero (1984) and Salemme and Miotti (1987)

PERIOD	EPOCH		14C yrs. B. P.	CLIMATIC OSCILLATIONS (Southern South America) Events	Temperature	Humidity, Palaeowinds	RELATIVE SEA-LEVEL CHANGES	AREA OF THIS STUDY	FAUNA VEGETATION & ENVIRONMENTS (comparison with present)
QUATERNARY	HOLOCENE	Late	500	Little ice age	cool				Similar to present
			1,000		~ present	anticlockwise circulation			Brazilian fauna
			4,500	Neoglaciations	cool dry semi-arid		Low s.l. trend		Patagonian mammals Northwards displacement of subtropical faunas, xeric vegetation
		Middle	5,000 7,000	Hypsithermal	WET WARM H, STR, TR	humid and warm winds; >rainfall; well developed soils	TRANSGRESSION (+5 m a.p.m.s.l.)	LAS ESCOBAS FM. (M)	Subtropical invertebr. and vertebrates; humid steppe
			8,500	Amelioration		interruption of eolian activity; lower rainfall			No Pleistocene mammals; human occupation.
		Early	10,000						
	PLEISTOCENE	Late	11,000	Younger Dryas ?	cool dry	windy	Low s.l. stand (-115m)	DESTACAMENTO RIO SALADO FM.	Cooler and lower saline molluscs; halophytic vegetation Beginning of vertebrate massive extinctions
			15,000 14,000 18,000	Glacial maximum	VERY COLD VERY DRY	cold and dry winds eolian activity (silts and fine sands)	NAHUEL HUAPI GLACIATION (In the Andes)	Pampiano Formation	
			26,000- 36,000 ?	Late glacial interstadial	moist mild dry cold		Interstadial ? (+3-6m a.m.s.l.)	PASCUA FM. (M)	Lujanense Mammal age Similar to present molluscan fauna; slightly warmer
				Last Interglacial	warm		LAST INTERGLACIAL ?	Pampiano Formation (FL - E)	Insufficient molluscan evidence

References:
M = marine sediments; FL =fluvial sediments; E = eolian sediments

H = humid; STR = subtropical; TR = tropical least 2 ka younger than the chronology of this event for other areas of the southern hemisphere (11,500–9500 BP; Burrows, 1979). Although the scarcity of appropriate material is problematical, further radiocarbon dating of these deposits along the Bonaerensian coastal plain is required to obtain a better chronological control of late-Glacial to early Holocene climatic events in the area and establish whether they correspond to a reversal within the warming trend following the last Glacial Maximum. Whether or not the marshy deposits of Destacamento Río Salado correspond to the Younger Dryas cool event may be elucidated by recently initiated trace element and oxygen isotope studies of bivalve shells.

'Platense' Stage

This name was used by Doering (1892) for lacustrine deposits but ever since it has been used for several kinds of sediments by subsequent authors. Referring to shelly marine deposits, widely distributed along the coast of Buenos Aires Province, the name was first used by Ameghino (1889). He placed them in the late Pleistocene, above the Belgranense (Pliocene) and the Querandino (mid-Pleistocene) (Table 1).

Frenguelli (1957) used the term 'Platense stage' for littoral sandy beach ridges at 5 m above m.s.l. deposited along Samborombon Bay in the Holocene while sea level fell (Fig. 2). Fidalgo (1979) defined the same deposits as the Cerro de la Gloria Member of the Las Escobas Formation formed during the Holocene climatic optimum (Fig. 4; Table 6). Tricart (1973) also named them 'Platense' but placed them in the late Pleistocene, considering that only the lowest at 1.5 m above m.s.l., the most modern ridges, formed during the Flandrian transgression which he named the Dunquerkiano. Recent authors established that the latter constitute a small erosional step formed during a minor sea level fall at ca. 3500 ^{14}C years BP during the same Holocene transgression (Codignotto and Aguirre, 1993).

Several groups of invertebrates are well preserved in these deposits. These are corals, polychaetes, bryozoans, crustaceans (Brachyuran dactylae, ostracods and cirripeds), echinoderms (pennatulids), foraminiferids and molluscs (polyplacophorans, bivalves, gastropods).

HOLOCENE RIDGES

Marine 'Platense' (Frengueilli, 1957) = the Cerro de la Gloria Mb. of the Las Escobas Formation (Fidalgo, 1979) = marine facies of Mar Chiquita Formation (Schnack *et al.*, 1980).

The Holocene beach ridge facies is composed of coarse to medium sand and abundant whole and comminuted molluscan shells, generally forming nearly parallel domed ridges, subparallel to the present coastline, progressively younging towards the coast (Fig. 12). The ridges are approximately 20–30 m wide, up to 5 m high and at an altitude of some 4.5–5 m above m.s.l. They extend for some 120 km in the Samborombon Bay area and occur 2.5 to 4.3 m above m.s.l. in Mar Chiquita. They can be found 5 km inland in the area of Punta Piédras, 30 km inland in southern Samborombon Bay, and 2.5 km in Mar Chiquita. Exposures are found from Buenos Aires city in the north to Mar Chiquita and again around the Bahía Blanca Estuary (ca. 39° S). They also occur in Patagonia and Tierra del Fuego where they are known under different names (Codignotto, 1983; Farinati, 1985a, b; Rutter *et al.*, 1990; Gordillo, 1991; Gordillo *et al.*, 1993). Similar Holocene beach ridges are found northwards in Uruguay (Sprechmann, 1978), Brazil (Martin *et al.*, 1986, 1993) and Guiana (Altena, 1971).

Radiocarbon Ages

Many radiocarbon ages have been obtained in the study area and were used in a chronological reconstruction of past shorelines by Schnack *et al.* (1982), Violante (1988), González and Weiler (1988b, 1990) and Codignotto and Aguirre (1993). A synthesis of the published ages for the marine Holocene of the area, between 1300 and 7800 BP, and for similar synchronous deposits along eastern South America from Brazil to Tierra del Fuego is given in Table 2.

In Samborombon Bay, the ages of the beach ridges range from 2000 to 6890 BP (Codignotto and Aguirre, 1993) and decrease seaward. In the Mar Chiquita area the ages fluctuate between about 3000 and a maximum of 5000 BP with dates of ca. 1400 to 2500 BP for the estuarine facies of Mar Chiquita Fm. (Fasano *et al.*, 1982). In the south of Buenos Aires Province, the age of the beach ridges around Bahía Blanca at some 8–10 m above m.s.l., range from ca. 3000 to 7500 BP and also show a general decreasing age (Farinati, 1985b).

The oldest radiocarbon ages for the Holocene in Buenos Aires Province correspond to the maximum transgressive phase dated at ca. 7000–7600 BP in estuarine facies (Fasano *et al.*, 1987). For the study area they correspond to the ridges from Punta Indio at 7600 BP (Cortelezzi and Lermann, 1971 and references therein) and the coastal lagoon facies in Samborombon Bay in the Canal 18 Member, at ca. 6700 BP (Fidalgo *et al.*, 1981).

Figure 14 shows a preliminary sea-level curve based on a synthesis of all available data from the Bonaerensian littoral and a comparison with other data from the Atlantic coast of South America. Before 8000 BP the sea level is supposed to have been lower than present, reaching its maximum between 7000 and 5000 BP in Tierra del Fuego and between 6000 and 5000 in Brazil and southeastern Buenos Aires Province. In the study area a peak of the transgressive maximum seems to have taken place around 7600 BP, followed by a more or less stable high sea level until 5000–4000 BP, all this period corresponding to the Hypsithermal. Similar ages for the Holocene climatic optimum have been recorded in Australia, New Zealand, southern Africa and the Argentine plains (Iriondo and García, 1993; Burrows *et al.*, 1976; Avery, 1993). The post-Hypsithermal falling sea-level trend in the study area probably took place after 4000 BP and the last, smaller, sea-level rise occurred after ca. 3000 BP.

Amino Acid Dates

Amino acid estimations of raised beach deposits in different coastal areas have also proved to be a useful tool for the interpretation of the evolution of the Quaternary shorelines related to sea level fluctuations. For example, this has been done in Britain by Bowen *et al.* (1985) and Bowen and Sykes (1988) and in Perú and Chile by Hsu *et al.* (1989), in Australia by Murray-Wallace and Hobart (1991) and in Patagonia by Rutter *et al.* (1990). This methodology was recently applied to shells of five bivalve genera (*Mactra, Macoma, Tagelus, Corbula, Noetia*) from the study area collected at Punta Indio, Samborombon Bay and Mar Chiquita. The D/L ratios obtained allow us to distinguish the older beach ridges of Punta Indio and Punta Piedras from a set of slightly more modern ones which may have been accumulated within short subsequent periods of approximately 2000 to 1000 years (Aguirre *et al.*, *in press*).

Table 3 shows the results of the D/L ratios on various molluscs from various Holocene ridges and a number of localities. At Punta Indio, the minimum ratio from 10 valves of *Mactra isabelleana* was 0.110, while at locality 7 (Fig. 1) in Samborombon Bay from 5 valves of the same species the minimum D/L ratio was 0.048. At Mar Chiquita, locality 24, 5 valves of the same species gave a minimum D/L ratio of 0.053. A similar trend in the D/L ratios is seen for *Tagelus plebeius* with ratios of 0.123 to 0.173 on 10 valves from Punta Indio being higher than three valves from Mar Chiquita with a minimum ratio of 0.101. The same species from the lagoonal deposits of the Canal 18 Member of the Las Escobas Formation, at locality 11, yielded a minimum ratio of 0.053 for sample WA-8. Table 3 shows that *Corbula patagonica* follows a similar trend. Complete data are available in Aguirre *et al.* (*in press*).

Molluscs

Taphonomy and Composition

The shells which make up the ridges have been washed ashore from their original habitat and have suffered varying amounts of physical modification before being accumulated. There is, therefore, a mixing of specimens from several environments and generations and there are abundant fragmented shells (37–50%). In general they have a relatively 'Recent' aspect, many of them retaining their ornamentation, sheen and colour and are similar to the living representatives from the bonaerensian continental shelf and that of Uruguay and southern Brazil. Although less common, several bivalves are found with articulated valves and, in a few cases, in life position.

In the beach ridges of the Las Escobas Formation, the shells show a higher degree of fragmentation (Fig. 10) and abrasion than those of the Mar Chiquita Formation, which could be explained by assuming a longer transport distance for the shells along the more extensive beach zone in Samborombon Bay. The biogenic content of the beach ridges is high (44–51%; Figs 6–9, Table 4), compared with the Holocene estuarine facies occurring in the same area (Canal 18 Member), where clastic sediment dominates (> 80%). The following molluscan taxa and their percentages are characteristic of the beach ridge facies:

Gastropoda:

Crepidula dilatata (1.50%), *Natica isabelleana* (0.01–0.4), *Triphora nigrocincta* (0.75), *Urosalpinx rushi* (0.04–0.4), *Zidona angulata* (0.04–0.07), *Adelomelon brasiliana* (0.02), *olivancillaria brasiliana* (0.02), *Olivancillaria auricularia* (0.03), *Olivancillaria carcellesi* (0.02–0.4), *Buccinanops lamarckii* (0.01–0.5), *Buccinanops gradatum* (0.02), *Buccinanops deformis* (0.01–0.2), *Buccinanops globulossum* (0.02–0.05), *Anachis* cf. *avara* (0.05–1.20).

Bivalvia:

Noetia bisulcata (0.03–7.3%), *Anomalocardia brasiliana* (0.1–0.43), *Petricola pholadiformis* (0.7), *Erodona mactroides* (0.1–20.6).

These, and other species, compose recurrent groups previously defined by cluster analysis as 'associations' (*sensu* Kauffman and Scott, 1976, p. 21) whose distribution within the various localities and their ecological significance were discussed by Aguirre (1990, 1993b).

Association 1: Mactra isabelleana (*X* = > 60%), *Ostrea* cf. *equestris* (Bivalvia); found mainly in loc. 6, 7, 10 (and less in 12).

Association 2: Erodona mactroides, Abra aequalis, Macoma cf. *uruguayensis, Tagelus plebeius* (Bivalvia) *Olivancillaria auricularia, Olivancillaria carcellesi* (Gastropoda) most abundant in loc. 1, 4 and 12.

Association 3: Anachis obesa, Dorsanum moniliferum, Triphora nigrocincta, *Epitonium georgettinum, Zidona angulata, Crepidula protea, Urosalpinx cala, Crepidula aculeata, Crepidula dilatata patagonica, Urosalpinx rushi, Buccinanops cochlidium* (Gastropoda); *Noetia bisulcata, Diplodonta patagonica, Pitar rostratus, Entodesma patagonica* (Bivalvia), especially in loc. 2 (Punta Indio).

Association 4: Adelomelon brasiliana, Buccinanops gradatum, Olivancillaria brasiliana (Gastropoda), *Anomalocardia brasiliana* (Bivalvia), in loc. 7.

Association 5: Buccinanops sp., *Buccinanops globulossum, Buccinanops deformis, Mangelia* sp., *Turbonilla fasciata, Natica isabelleana* (Gastropoda); in loc. 6 and 7.

Association 6: high percentages of *Littoridina australis* associated with *Crepidula patagonica, Crepidula* cf. *onyx, Olivella puelchana* (Gastropoda) and *Mactra* aff. *isabelleana, Bachidontes rodriguezi, Carditamera guppyi* (Bivalvia); mostly in loc. 22 and 24.

Palaeoenvironments

The quantitative analysis (Figs 10 and 11) of the Holocene molluscan fauna indicates that the environmental conditions during deposition of the northern (Las Escobas Fm.) and southern (Mar Chiquita Fm.) sectors of the study area were different. In the northern sector, from

Punta Indio to General Conesa (Fig. 11), the high percentage of infaunal taxa (Fig. 10) indicates a habitat of soft substrates and polyhaline to poly-euhaline salinity, in the upper infralittoral, in waters of relatively low energy, probably in an open bay. Conversely, in the Mar Chiquita area the higher percentage of epifaunal taxa (mostly typical of hard bottoms), the lower diversity and the dominance of the brackish water gastropod *Littoridina australis*, suggest a shallower hard bottom environment along supralittoral and intertidal zones (Aguirre, 1991).

The molluscs from the beach ridges of Punta Indio may have lived in an environment entirely different from that obtaining in Samborombon Bay. Codignotto and Aguirre (1993) suggest that these beach ridges were minor barrier spits and that the environment was one of high energy within the intertidal to shallow infralittoral, with more varied substrates (mainly hard bottom) and euhaline to poly-euhaline salinity. They probably formed during the peak of the climatic optimum around 8000–6000 BP, as suggested by the older radiocarbon dates (> 7000 BP) and higher amino acid ratios. This is supported by the molluscan palaeoecology which is of a more diverse fauna and with highest percentage of warm water marine elements (ca. 42%).

The Holocene coastal lagoon facies, the Canal 18 Member of the Last Escobas Formation, contains abundant shells of *Tagelus plebeius* in life position and only a few shells of other bivalves (*Mactra isabelleana, Raeta plicatella, Macoma uruguayensis, Corbula patagonica*). It clearly represents a lower salinity than the ridges, and a low-energy environment with fine substrates. In agreement with this, the ostracods from the same sediments are a brackish assemblage without important marine species which occur in the ridges.

Similar deposits from Mar Chiquita (loc. 25; Fasano *et al.*, 1982) and Bahía Blanca (Farinati *et al.*, 1992; Fig. 12) contain abundant valves of *T. plebeius*, forams and ostracods typical of brackish environments and represent the climatic optimum of some 6000 ^{14}C years BP (González *et al.*, 1983).

Microfossils

The ostracod fauna as a whole belongs to a mixed environment (brackish to brackish-marine), the taxonomic composition of the ridges from Punta Indio and Punta Piedras suggesting a higher salinity (marine to brackish-marine) than the rest. Whatley and Cholich (1974) described a new ostracod genus (*Pampacythere*, Limnocytheridae) from the Holocene beach ridges between Buenos Aires and Mar del Plata, and suggested their original habitat in oligohaline-meiomesohaline brackish-water conditions.

The ostracods and forams mentioned from the Holocene of Mar Chiquita and Bahía Blanca and the species recovered from the ridges of Samborombon Bay (Table 5) represent a low diversity microfauna typical of a mixed environment (Fasano *et al.*, 1982; González *et al.*, 1983; J. Haynes, *pers. commun.*). The evidence presented here is confirmed by the same ostracods identified by Toy (1985) and Chadwick (1986) from the continental shelf of Argentina, information on living ostracods from the bonaerensian lagoons (Ramírez, 1966) and comparison with the living forams in the area of the Rio de La Plata (Boltovskoy and Lena, 1974).

HOLOCENE ENVIRONMENTAL CHANGES

The living molluscan communities recorded along the Bonaerensian littoral (Aguirre, 1990) differ qualitatively but mostly quantitatively from the subfossil assemblages sampled in the beach ridges. These differences are interpreted as a consequence of climatic and sea-level changes which have occurred during the last ca. 8–7 ka in the study area. These correlate with those recognized in other areas of the southern hemisphere (Partridge, 1993; Avery, 1993; Burrows, 1979).

The mid-Holocene molluscan fauna, typical of marginal marine environments, is generally of low specific diversity and high dominance, a characteristic of unstable habitats (Scott, 1976). In Samborombon Bay, the lowest diversity, in coincidence with the highest dominance and lowest inferred salinity (mixohaline), corresponds to the innermost beach ridges which may (loc. 12 and 13; Figs 5, 11 and 13) have been barrier islands. These probably formed during the maximum of the mid-Holocene transgression ca. 7000 BP in Buenos Aires Province while the transgressive maximum in other areas of eastern South America has been recognized between 7 and 5 ka BP (Fig. 13). The remaining mid-Holocene deposits along Buenos Aires Province (i.e. Puerto Quequén, Bahía Blanca), the molluscs (Table 4), also suggest mixing waters, but not typically marine environments as the modern adjacent nearshore.

During the mid-Holocene, with relatively stabilized high sea level, the mixing of marine and oligohaline waters may have not been completed. As a consequence of the post-glacial global temperature rise, large quantities of ice melting in the South Atlantic (Isla, 1990), together with increased rainfall and the enhanced importance of the Salado and Samborombon rivers in the north, may have been responsible for greater freshwater influence in the area than today. In addition, the diluting influence of the palaeo Rio de la Plata along the coastal area studied must not be overlooked.

Tricart (1973) had already pointed out that the Holocene interglacial corresponded to a pluvial epoch. Highest temperature and precipitation were reported by Fernández and Romero (1984) for synchronous deposits from Chascomus, a few km westwards of the ridges, on the basis of palynological evidence of humid steppe development and some rain forest species. The post-glacial ice melting was also regarded as a cause for most of the Holocene environmental changes occurred in the southern hemisphere (Burrows, 1979) which apparently differ from those of the northern hemisphere. The fluctuating sea level trend in the southern hemisphere *versus* the rising sea levels in the northern hemisphere and the climatic optimum occurred in the southern hemisphere ca. 3000 years earlier than in the northern hemisphere (Isla, 1990; Clapperton, 1993).

Another outstanding difference between mid-Holocene (ca. 7600–4500) and modern marine environments (Fig. 13) is that most of the fossil molluscan associations lived in shallow oceanic waters of higher temperature than the present. The percentage of warm-water molluscs was higher during the mid-Holocene (35%) than today (ca. 14%) and several of them (bivalves and gastropods) do not now live in the adjacent nearshore but have been displaced northwards (Aguirre, 1993a), probably since ca. 4500–4000 BP (Fig. 14). Similar molluscan evidence for the Hypsithermal was reported from the mid-Holocene of southeastern Uruguay by Sprechmann (1978) and for the Sea of Japan by Lutaenko (1993). Iriondo and García (1993), on the basis of past atmospheric circulation patterns, established the Holocene climatic optimum for the Argentine pampas at ca. 5000–3500 and in many other Argentinian Holocene deposits this event was recognized between 6000 and 3500 BP. Rabassa (1987) placed it at ca. 6000–4500, followed by a climatic deterioration with alternating periods of glacier readvancements in the southern Andes. In South Africa, similar evidence for the shift of oceanic water masses and the convergence zone was reported during the mid-Holocene climatic optimum (ca. 7000–6500 BP) by Partridge (1993). In other areas of the southern hemisphere the Hypsithermal has been placed at ca. 8000–6500 BP (Burrows, 1979). A synthesis of the more reliable ^{14}C dates from our study area (Fig. 13) indicates that the transgressive maximum (> 7000–5000) may correspond to this warmer period.

The post-Hypsithermal climatic deterioration and falling sea-level trend that began about 4500 BP can be regarded as the main causative factor in the changes occurred in the marine and continental biotas of this area (Table 6). The sea surface temperature decline probably allowed the greater influence of the Falkland cold current into the Bonaerensian littoral and a northwards shift of the Subtropical–Subantarctic Convergence, resulting in the northwards displacement of some marine taxa (Aguirre, 1993a).

All available information confirms that, with respect

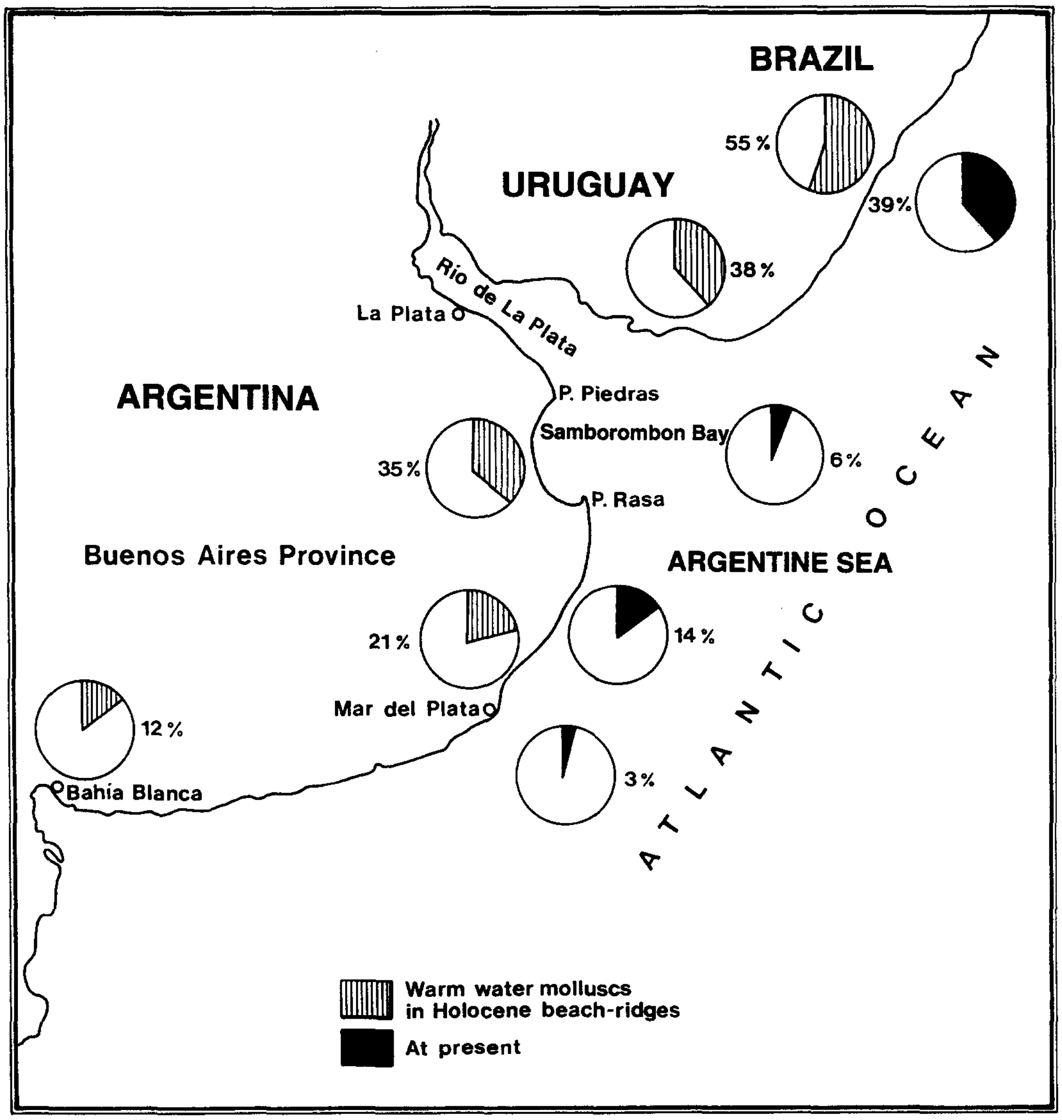


Fig. 13. Quantitative comparison of warm-water molluscs from the Holocene beach ridges and the Recent oceanic littoral (after Aguirre, 1993a).

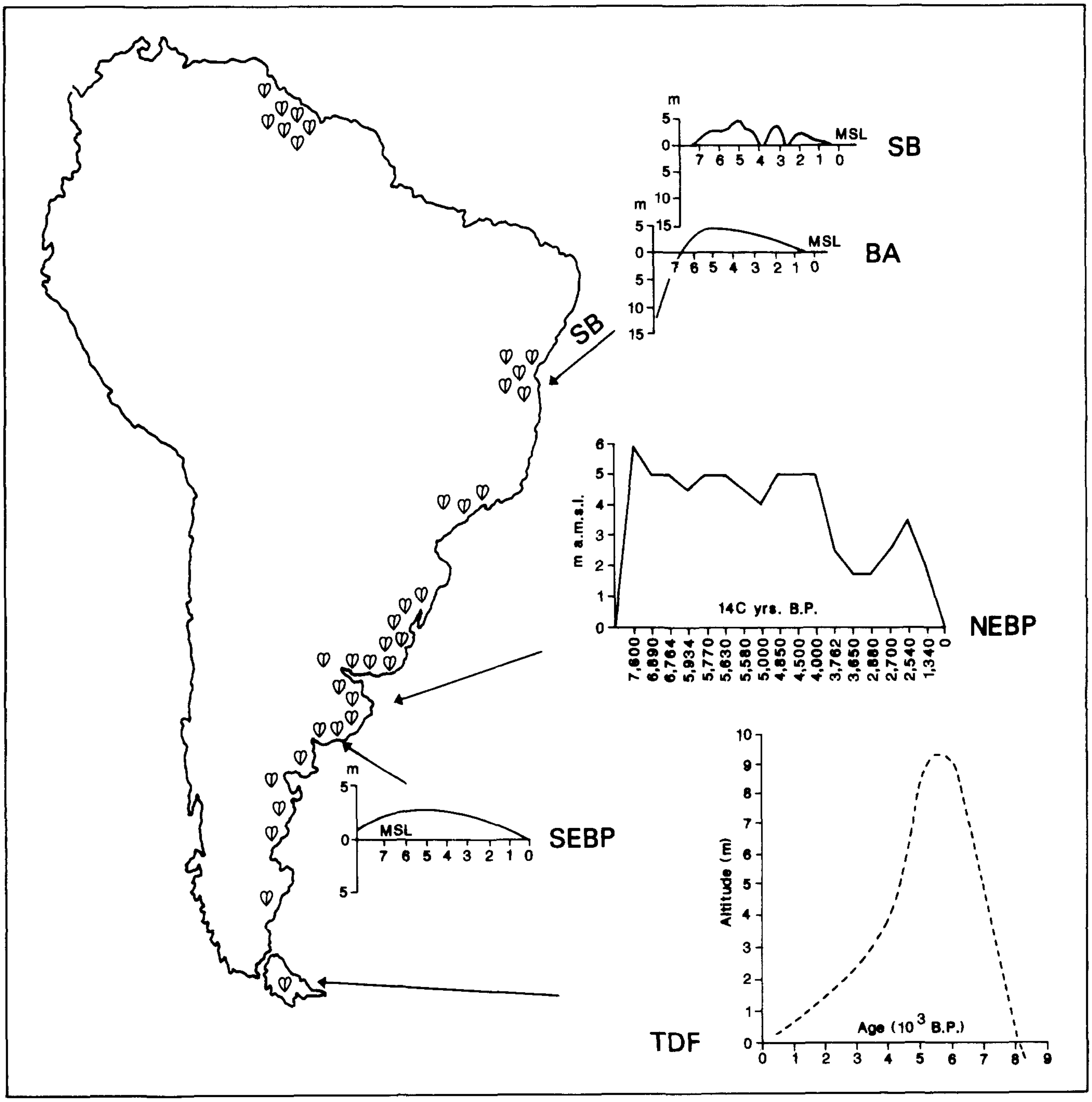


FIG. 14. Distribution of Holocene marine deposits along eastern South America. Sea-level changes in Brazil (SB = Salvador de Bahía; Martin *et al.*, 1987; BA = Brazilian average; Suguio and Tessler, 1984), northeastern Buenos Aires Province (NEBP, this paper; see also Table 2), southeastern Buenos Aires Province (SEBP, Schnack *et al.*, 1987) and Tierra del Fuego (TF, Gordillo *et al.*, 1993) (modified from Schnack *et al.*, 1993).

to the Mollusca, changes in the composition of the fauna within the various beach ridges and between the fauna of the mid-Holocene and the Recent, can be attributed to global temperature change.

Additionally, recent distributional patterns of ostracods recovered in the mid-Holocene deposits (Whatley and Cholich, 1974; Whatley *et al.*, 1987, 1988; Toy, 1985; Chadwick, 1986) also suggest a northward displacement after the climatic deterioration due to the greater influence of the cold Falkland current. This supports the post-Hypsithermal cooling event revealed by the molluscs and mammal faunas from the bonaerensian area (Table 6).

ORIGIN AND EVOLUTION OF THE HOLOCENE RIDGES

Low wave energy, low terrigenous sediment supply and low coastal relief are among the major factors leading to the accumulation of shell concentrations (Meldahl, 1993). The origin of sand ridges on continental shelves in different parts of the world has been explained by several hypotheses, but apparently their formation, orientation and distribution cannot be explained by a single model.

The mode of formation of modern ridges has been studied in detail along the Atlantic coastal plain of North America (McBride and Moslow, 1991; Reading, 1986).

In this area, sand shore-parallel ridges were developed on the inner shelf and shoreface after intense storms, always being preceded by considerable sand concentrations. Most of them (91%) were found along barrier island shorelines and are some 100 m long, 10 m high and 10–30 m wide; similar to those of the ridges studied in the area of Samborombon Bay. In Northern Ireland, Carter (1986) proposed two models for beach-ridge formation. One model explained their origin during the high water mark of spring tides through the migration of swash bars 30–55 days after a storm. The other revealed that when the sediment which had accumulated in nearshore bars moved alongshore, it caused bar elongation and the beach ridges emerged on to the upper beach 90–150 days after a storm. Nearshore bars along the North Carolina littoral were studied by Sallenger and Howd (1989) who concluded that they could form not only in the offshore where the break point is placed, but could develop and migrate offshore while being in the inner surf zone.

In South America, Sandweiss (1986) explained the origin of the Holocene beach ridges along the coast of Peru as a consequence of episodic events of large magnitude (i.e. past ENSO = El Niño Southern Oscillation events) on the basis of such sedimentological evidence as well sorted sand instead of larger clasts and geomorphological evidence of small numbers of different distant beach ridges. He assumed that episodes similar to the present ENSO, characterized by rainfall anomalies and changes in prevailing wind direction (i.e. different atmospheric circulation patterns which determine reversals of the longshore sand transport) could have caused massive pulses of sediment which formed those beach ridges. Although previously ENSO conditions were only known to take place along the Pacific coast of South America (Ortlieb *et al.*, 1989; Macharé and Ortlieb, 1990), past ENSO-like conditions have recently been recognized in the southwestern Atlantic (ca. 4000 BP; Martin *et al.*, 1993) revealing past environmental conditions similar to the modern ENSO off the coast of Perú and to the palaeo-ENSO (ca. 5000 BP) recognized by Sandweiss (1986) in the same area.

For the study area, the mode of formation of the sand shell ridges has not been definitively established. It is not clear whether all the ridges accumulated in the same way and in which zone of the beach profile they accumulated. They could have formed in the backshore and shoreface by storm waves action (supratidal and intertidal) or in the shoreface (sublittoral) emerging afterwards while sea level was falling. They could be either regressive or transgressive in origin. Along the coastal plain of the Rio de La Plata, Urien and Ottmann (1971) considered the successive beach ridges to be regressive and formed by storm waves, while at the same time (ca. 6000 BP) a complex of sublittoral bars from the SW to the NE formed a large lagoon between the bars and the coast. In the Samborombon Bay area, the ancient ridges have been interpreted as having formed like typical shallow beach deposits or sublittoral bars (Fidalgo *et al.*, 1973; Fidalgo, 1979; Spaletti *et al.*, 1987), by storm waves (Spalletti *et al.*, 1987), either of a regressive (Fig. 4; Frenguelli, 1957; Fidalgo, 1979) or a transgressive origin (Tricart, 1973). Codignotto and Aguirre (1993) described the Samborombon Bay ridges as barrier islands and those from Punta Indio as minor barrier spits, both of regressive origin (Fig. 12). Around Mar Chiquita, the ridges were interpreted as being formed by storm waves during regression (Fasano *et al.*, 1982) and as regressive barrier spits (Codignotto and Aguirre, 1993). In Bahía Blanca, they show strong geomorphological similarities to cheniers (i.e. similar width and height) but lack their typical biconvex cross-section and fine sediments and are interpreted as having formed by transgressive–regressive processes (Aliotta and Farinati, 1990; Farinati, 1985b).

A transgressive model for the origin of the beach ridges would imply the preservation only of the youngest generation of ridges, as the oldest (previous) ones would have been eroded in a landwards direction while the sea level was rising. If the ridges were formed during the regressive phase of the transgression, then a series of ridges would have been preserved, progressively younger 'rows' being accumulated seaward (the oldest inland) as the destructive agency of the littoral retreated oceanwards. The available evidence allows us to assume that the ridges of the study area were formed during fluctuating sea-levels of a Holocene falling sea-level (Figs 4 and 13). Our present knowledge of stratigraphical relationships, geomorphology, and the fact that the majority of the radiocarbon ages decreasing seaward, suggests a regressive model for their origin, accumulating during subsequent phases of progressively lower sea level stands since ca. 6500 BP.

North of Samborombon Bay, the beach ridges of Punta Indio–Punta Piedras yield the oldest radiocarbon dates and highest amino acid ratio for the entire study area. They also exhibit a different geometry and apparent truncation of their alignment (Codignotto and Aguirre, 1993; Fig. 5) and a very different fauna in comparison with the remaining Holocene ridges and with the neighbouring nearshore. All this reinforces their greater age and deposition during different environmental conditions, i.e. changes in the sand transport direction during warmer oceanic conditions. By contrast, the easternmost (younger) ridges further south along Samborombon Bay may have formed during a longshore drift similar to the present regime in the sublittoral zone of the Argentine Sea (Spalletti *et al.*, 1987).

Reversals of the longshore sand transport were recorded in the coastal area of central Brazil for similar and synchronous mid-Holocene beach ridges. They were described as short-term events, frequent before 3900–3600 BP, reflected by the different shape of the beach ridges (geometry, location and progradation direction), and probably a consequence of perturbations in the past atmospheric circulation pattern. The Holocene seasonality (Markgraf, 1989) observed in different regions of South America is thought to have been caused by this kind of phenomena (Martin *et al.*, 1993). This hypothesis is also in agreement with changes in the ocean–atmosphere system as a possible cause for climatic changes. These changes result in greater insolation, greater impacts of freshwater on the ocean's salinity distribution and different oceanic circulation patterns (Broecker and Denton, 1990).

Whether the formation of the ridges took place as supratidal or infralittoral bars remains unclear. The palaeoecology of the molluscan fauna provides some supplementary information since, along the ridges of Samborombon Bay, cross-bedded facies are common in most beds (typical of subtidal–intertidal deposits; Reading, 1986; Fidalgo *et al.*, 1973; Spalletti *et al.*, 1987) which are composed mainly of infaunal taxa, typical of the infralittoral (Fig. 10). Therefore, they could have had a sublittoral origin. Conversely, in the ridges of Mar Chiquita, the abundance of epifaunal taxa (80–90%), typical of intertidal or supralittoral high energy environments on rocky substrates, would support their deposition along the foreshore or backshore zones.

CONCLUSIONS

(1) Along the northeastern Bonaerensian coastal area during the **mid to late Holocene** (marine 'Platense', Las Escobas Fm.), both the molluscs and the microfossils (mainly ostracods) from the beach ridges at 2.5–4.5 m above m.s.l.; 7600–2500 BP, lived in a mixed environment with a salinity below that of marine waters as in the adjacent nearshore. The molluscs from the **mid-Holocene ridges** suggest mostly polyhaline to polyeuhaline waters of an open bay for the northern area (Samborombon Bay), whereas in the south (Mar Chiquita) they lived in brackish to polyhaline waters of higher energy littoral environments.

(2) A higher than present sea surface temperature reflecting the climatic optimum of ca. 8000–4500 BP characterized the mid-Holocene along the study area, the peak of the Hypsithermal corresponding to beach ridges deposited ca. 8–6 ka. Similar and approximately synchronous shelly marine accumulations were deposited along the coastal plain of eastern South America from Tierra del Fuego to central eastern Brazil.

(3) On the basis of the molluscan evidence the post-Hypsithermal climatic deterioration and falling sea-level trend began in the study area after ca. 4500 BP, in agreement with evidence from other areas in Argentina (Rabassa, 1987; Iriondo and García, 1993). This event can be regarded as the main controlling factor, strongly affecting both the marine and continental biotas of this area (Table 6).

(4) A regressive origin for the ridges is assumed, on the basis of their preservation and radiocarbon ages: different generations of beach ridges found along the coastal area show radiocarbon ages which in general decrease seaward. In Punta Indio they were deposited under different environmental conditions at the peak of the Hypsithermal, possibly during a period of reversal in the atmospheric circulation pattern, as revealed by the different geometry and alignment of the ridges (Fig. 5), older D/L and radiocarbon dates (Tables 2, 3) and a different fauna than the remaining Holocene ridges.

(5) Very different palaeoenvironments characterized this coastal area during the **Pleistocene–Holocene** boundary ('Querandinense', Destacamento Río Salado Fm.). The molluscs and ostracods are indicative of cold and low salinity environmental conditions. Similar evidence from other localities in South America were attributed to the Younger Dryas chronozone of the northern hemisphere, but correlation with this event in the study area needs to be confirmed by the trace element and isotope analysis of the shells. These analyses are currently in progress.

(6) The **late Pleistocene** marine outcrops (Belgranense, Pascua Fm.) of Buenos Aires Province represented by beach ridges or beach deposits are poorly exposed and restricted. They seem to correspond to an interstadial during the Last Glaciation (isotope substage 3?) on the basis of the geological and faunal evidence available. However, the available dates for these sediments (ca. 26–37 ka BP) would most likely argue against a higher than present sea level as indicated by the oxygen isotope record and most of the glaciological evidence available for South America.

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