

Palaeobiogeography of the Holocene molluscan fauna from northeastern Buenos Aires Province, Argentina: its relation to coastal evolution and sea level changes

Marina L. Aguirre

División Paleozoología Invertebrados, Museo de Ciencias Naturales, Paseo del Bosque S/N°, 1900 La Plata, Argentina

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ABSTRACT

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In northeastern Argentina the Holocene (ca. 2500–6000 ^{14}C yr B.P.) benthic marine molluscan fauna from the Cerro de la Gloria Member of the Las Escobas Formation represents a higher sea-level stand (approximately 4–5 m above m.s.l.) than the present one and belongs to an original shallow water environment. Most of this fauna (48%) belongs to the Argentine Zoogeographic Province while part of it (12%) is shared with the Magellanian Province. The rest of the taxa are cosmopolitan (5%) or belong to the Caribbean, Antillean and Brazilian provinces (35%). The latter are considered stenothermic warm-water indicators which in the present northeastern marine shelf of Argentina are scarcer (6–14%), most of them ranging from the Antilles to southern Brazil or northeastern Uruguay. It is a thermally anomalous molluscan fauna which is a consequence of local coastal palaeogeography and global mid-Holocene climatic change.

On that basis a higher sea-water temperature during the mid Holocene is inferred, probably due to a stronger influence of the Brazil Current which could have extended farther south- and westwards during the Hypsithermal.

The disagreement between the data presented here and the micropalaeontological data is still a problem to be solved, likely through critical systematic revisions of the foraminiferids and ostracods not included in this paper.

Introduction

Earlier work on Quaternary marine molluscs from the northeastern Buenos Aires Province include some monographic studies (D'Orbigny, 1842, 1846; Ihering, 1907; Carcelles, 1944; Camacho, 1966; Castellanos, 1967) devoted to systematic analysis or ecology of some species. Aguirre (1988, 1990, 1991a, in press) carried out a systematic revision and a palaeoecological study of the entire molluscan fauna from the area which provided the basic data for the present paper.

Distributional, palaeoclimatic and palaeogeographic patterns are now investigated, with special reference to the typically warm-limited taxa which could be considered the most useful tools in understanding past local conditions (see Valentine, 1958).

Beach ridges containing the abundant benthic molluscan fauna were formed during a higher eustatic sea-level stand corresponding to the last Quaternary marine transgression. They are approximately synchronous with many other similar deposits spread along the eastern South American coast from French Guyana to Brazil, Uruguay and in Mar Chiquita, Puerto Quequén, Bahía Blanca and Patagonia in Argentina. Radiometric dates based mainly on mollusc shells from those deposits suggest a maximum Holocene transgressive phase at about 7000 yr B.P. followed by several subsequent moments of alternating high and low relative sea-level oscillations; their altitude being 4–5 m above m.s.l., except for areas (Bahía Blanca, approx. 38°S, 62°W, 10–12 m above m.s.l.; Patagonia, south of 41°S, 8–14 m above m.s.l.) of epeirogenic uplift (Sprechmann, 1978;

González and Weiler, 1983; Farinati, 1985a,b; Turcq et al., 1986; Martin et al., 1986; Suguio et al., 1986; Isla et al., 1986; Fasano et al., 1987; Prost, 1990). They are also coincident with high sea-level stands of other areas (Northern Europe, Japan, New Zealand, northwestern Perú; see Mörner, 1984, 1990; Newman et al., 1984; Pirazzoli, 1984; Ortlieb et al., 1989a,b).

Palaeoecological work on the molluscs of these deposits (Aguirre, 1988, 1990, 1991a,b) showed that the composition and relative abundance of taxa differ from those of the existing modern shallow water (inner shelf) associations in the adjacent Argentine Sea. Moreover, analyzing the present position of each discriminated species, differences were revealed between modern and fossil ranges: a thermally anomalous molluscan assemblage ("TAMA" of other authors) may be recognized.

Similar situations have been used in the Quaternary of other regions (e.g. Valentine, 1958; Hall, 1960; Addicott, 1966; Beu, 1974, 1975; Kanazawa, 1990; De Vries and Wells, 1990; Diaz and Ortlieb, 1991, 1992; Perrier et al., 1992, among others) to draw palaeoecological conclusions and to recognize ancient coastlines.

It is well known that differences in marine climates are important factors in the geographic differentiation of animal distributions (Knox, 1960; Addicott, 1966; Ekman, 1967; Briggs, 1974; Boltovskoy, 1979), and that most of the living taxa with a fossil record had the same or similar ecological tolerances as their modern representatives (Hall, 1960). Leaving aside other ecological parameters such as substrate type and salinity (Aguirre, 1988, 1990, 1991a), distribution of taxa has been controlled by temperature. It is here assumed that the thermally anomalous assemblages recognized here are a consequence of local coastal palaeogeography and of global mid-Holocene climatic change.

Finally, the studied molluscan assemblages provide a way of testing the assumption that the Las Escobas Formation (Fig. 1) was formed in Hypsithermal times during a high sea-level stand under warmer, humid conditions (Tonni and Fidalgo, 1978; Fidalgo, 1979; Fidalgo et al., 1990).

Area of study

The area (Fig. 1 and 2) is located along a 170 km coastal area in Buenos Aires Province, comprising a relatively narrow littoral zone, 10–30 km wide, with its maximum extension in the southern Samborombón Bay region.

Along this area marine sediments, corresponding to at least two marine transgressions (Pleistocene, Holocene), are spread superficially. The deposits analyzed here belong to the lithostratigraphic unit known as the Las Escobas Formation (Fidalgo et al., 1973; mid Holocene, Present or Actual Interglacial), unconformably overlying continental sediments of the Pampiano Formation (Pleistocene) and sometimes over marine sediments of the Pascua Formation (marine transgression, Pleistocene) or the Destacamento Río Salado Formation (? lagoonal deposits, Holocene) and overlain by eolian sediments of the La Postrera Formation (Holocene). Radiometric (^{14}C ages obtained on molluscan valves showed a maximum of 7000–6000 yr B.P. The Las Escobas Formation is composed of two stratigraphic members, the one studied here being represented by ancient barrier islands (Codignotto and Aguirre, 1993) known as the Cerro de la Gloria Member; the Canal 18 Member represented by coastal lagoon deposits (see Frenguelli, 1957; Fidalgo, 1979; Fidalgo et al., 1973, 1981, 1990; Tonni and Fidalgo, 1978; González et al., 1986, 1988a,b; González and Weiler, 1983, 1990) (Fig. 1).

Fidalgo and Tonni (1978) and Fidalgo (1979, 1990) assumed, on the basis of synchronous continental sediments and vertebrate faunas, that the marine sediments of the Las Escobas Formation should have been formed during part of the Hypsithermal corresponding to warmer and humid conditions.

Las Escobas Formation: Cerro de la Gloria Member

This member is exposed along the coastal area from the surroundings of La Plata to southern Samborombón Bay (Esquina de Crotto); then southwards in M. Chiquita (Fig. 2) and in Bahía Blanca (ca. 38.5°S, 62°W). It is equivalent to the

Millions of Years (Harland et al., 1982)	Years ^{14}C B.P. (aproximat.)	Palaeomagn Ages	Era	Period	Geologic Epoch	Mammal Age (Pascual et al., 1965)	Climatic Oscillations (Tonni y Fidalgo, 1978, Fidalgo, 1979)		Glacial Cycle (Fairbridge, 1972, en Tonni y Fidalgo, 1978)	Study Area (Fidalgo et al., 1973)
							Major	Minor		
0.010	2-8000 7000	B	C	Q	HOLO CENE	L	Wet Warm	Wet Cold Very Dry Very Cold	Postglacial Actual Intergla- cial	LAS ESCOBAS FM. Dto. RIO SALADO FM.
					P		Dry Cold		Kataglacial PLENIGLACIAL	PAMPIANO FM. FL - P
0.730	30- 35000	S	E	U	PLEI STO CENE	J	Moist Mild Dry Cold	Anaglacial	INTERGLACIAL	?
					N		Wet Warm			PASCUA FM. M
		MATU YAMA								?
										PAMPIANO FM. FL - P

Fig. 1. Stratigraphic synthesis. Taken from Aguirre (1991).

beach ridge deposits studied northwards in Uruguay (Figueiras and Broggi, 1968–1973; Sprechmann, 1978) and in southern Brazil (Forti, 1969; Closs and Forti, 1971, Esteves, 1974; Godolphim et al., 1989) and southwards along the coastal area of Patagonia in Argentina (Feruglio, 1950).

The Cerro de la Gloria Member is represented by shelly accumulations conforming to typical low beach-ridge (high-energy) deposits, parallel or sub-parallel to the present seashore, in two or three rows, their crests reaching a maximum of 5 m above m.s.l., corresponding to a 3.5–3.7 km distance towards the coast, and decreasing seaward. They are composed of a medium to coarse sandy matrix with siltstones and caliches subordinate to a high molluscan content (Fidalgo et al., 1990). The sedimentological characteristics of the deposits, fluctuating between well sorted sand (loc. 7, 10) and very coarse sand (loc. 2, 4), reveal the presence of variable and synchronic environments, such as established by Godolphim et al. (1989) for similar Holocene sediments from southern Brazil.

Ages between approximately 6000 and 2500 yr B.P., based on ^{14}C dating of shell and bone

remains, were obtained by other authors (Cortelezzi and Lermann, 1971; Cortelezzi, 1977; Fidalgo et al., 1981; Figini et al., 1984; Figini, 1992; Gómez et al., 1985, 1988, 1992; Gómez, 1988; Codignotto and Aguirre, 1993) (Table 1).

These deposits may have had a regressive origin, as most authors assumed, which is supported by decreasing ^{14}C ages obtained for beach ridges situated in positions nearer to the present coastline (Frenguelli, 1957; Fidalgo et al., 1990; and Schnack et al., 1982 for synchronic deposits of M. Chiquita area). However, their way of formation has not been thoroughly analyzed yet, nor has a detailed sedimentological study for the whole area been made. Similar ridges along eastern South America apparently occur as a consequence of a marine regressive phase which began approximately or immediately after 7000 ^{14}C yr B.P. (Boltovskoy, 1979; Mörner, 1984; Suguio et al., 1986; Martin et al., 1986; Villwock et al., 1990; Clapperton, 1990).

Localities

Data on the 10 localities sampled faunally are presented in Table 1. They were selected by con-

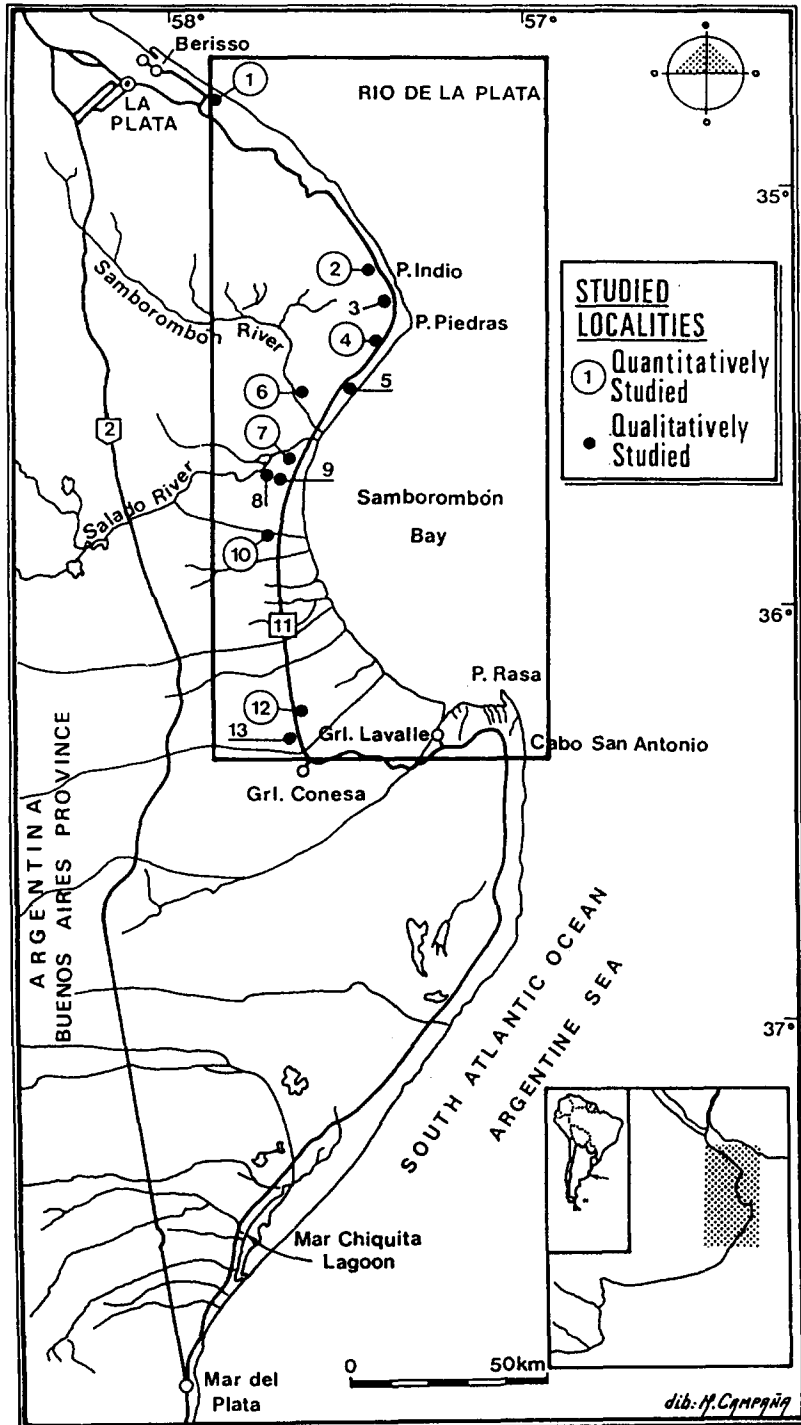


Fig. 2. Study area. General location of collecting area in northeastern Buenos Aires Province, Argentina.

TABLE 1

Geographic location of sample sites, ^{14}C ages, altitude and relative abundance of the warm-water molluscs

LOCALITY	GEOGRAPHIC LOCATION	H	D	^{14}C AGES	W
1	34 53'30"S, 57 49'30"W	2.52	2.8	4,760+120 3,900+70 (a) 4,260+70	16
2	35 11'S, 57 26'W	5-6	2,5	4,460 (b)	63
3	35 22'30"S, 57 19'30"W	5-6	0.76	7,600 (b)	53
4	35 26'30"S, 57 16'30"W	3.75	0.77	-	16
5	35 39'30"S, 57 19'30"W	2.5	1.5	7,890+343 3,762+244 (c) 4,067+224	11
6	35 42'30"S, 57 22'30"W	4.25	3.5	-	37
7	35 46'10-20"S, 57 24'30"W	4.5	3.5	3050+150 (e) 4,920+216 5,934+222 (c) 6,056+204	42
10	35 58'20"S, 57 27'W	5-6	7.01	4,100-4,900 (d)	32
12	35 58'20"S, 57 21'W	5	ca.20	-	26
13	36 22'40"S, 57 21'35"W	5	ca.30	-	32

REFERENCES:

H: altitude (in m above m.s.l.)
D: distance to the present shoreline (in Km)
W: percentage of warm-water species

a: from Cigliano (1963)
b: from Cortelezzi & Lerman, 1971
c: from Fidalgo et al., 1981; Codignotto & Aguirre, in press
d: from Gómez et al., 1988
e: from Figini et al., 1984.

Note: in loc. 8 and 9, W was not quantified

sidering beach ridges at different distances to the present shoreline and because in most of them (except in locs. 12 and 13) radiometric ages had been obtained earlier by other authors (see Table 1).

Locality 11 (35°52'10" S, 57°29'15" W, just westwards of loc. 10) is not marked on the map (Fig. 2) as it belongs to a different facies: Canal 18 Member of the Las Escobas Formation (low-energy, coastal lagoon environment). These sediments extend farther away from the coast, the littoral beach ridges lying between Canal 18 Member and the present shoreline. Fidalgo et al. (1981) published three ¹⁴C ages from this facies obtained on whole clam shells, still joined by their ligaments, of *Tagelus plebeius* (Lightf.) in living position. The ages fluctuate between ca. 7000 and 6000 yr B.P. and constitute the only trustworthy dates of the Las Escobas in the area of study (due to the kind of biogenic material dated, its preservation and habit). They also provide an indication of the maximum transgressive episode.

Modern littoral area

The modern littoral area corresponds along the Rio de la Plata to the intermediate-fluvial (5–8‰), fluvio-marine (8–18‰) and oceanic (18–30‰) zones of the estuary (Boltovskoy and Lena, 1974; Sprechmann, 1978), while the oceanic sector belongs to the northern part of the Argentine Sea (South Atlantic Ocean) (34.5–38.8‰) (Fig. 2).

Along the Rio de La Plata, from Berisso to P. Piedras (Fig. 2), fine sands and silts are widespread; mostly clays are found along Samborombón Bay down to P. Rasa; whereas fine to medium-grain sand characterize the oceanic coast from P. Rasa to M. Chiquita and rocky shores are found locally in M. del Plata (see Olivier et al., 1968; Bastida et al., 1981; Aguirre, 1990).

On the other hand, the oceanic littoral is characterized by the presence of two shallow water masses: subtropical and subantarctic. The boundary for their convergence ("antiboreal" or "subtropical-subantarctic" convergence) has been approximately established at 38–40°S through the distributional patterns of several groups of organisms (see Ekman, 1967; Boltovskoy, 1981). These masses define the Brazilian (0–29°S; warm, sub-

tropical), Argentine (29–47°S in winter, 34–49°S in summer; warm-temperate transitional water mass) and Magellanean (43°S to Tierra del Fuego; cold, subantarctic) zoogeographic regions. Northwards of the Brazilian Province a tropical water mass was identified by Boltovskoy (1979) from micropalaeontological evidence.

In the littoral area of this study modern molluscan distribution is controlled by two shallow marine currents. The warm Brazil Current, a branch of the South Equatorial Current coming from the African coast, extends southwards down to Golfo San Matías (ca. 43°S) in summer and to Golfo Nuevo (ca. 47°S) in winter. The cool Malvinas Current, a branch of the West Wind Drift or Circumpolar Antarctic Current, extends northwards up to Río de Janeiro (ca. 23°S) in winter and to Rio de La Plata in summer. The oceanic shallow waters in the area are characterized by temperatures of 18–24°C (Boltovskoy, 1981).

Methods

Systematic collection of samples was carried out between Berisso and Grl. Conesa, mostly in natural exposures of ancient beach-ridges (Cerro de la Gloria Member of Las Escobas Formation). Molluscs were obtained from each level differentiated through detailed profiles measured in all the localities (Aguirre, 1988).

Stratigraphic and geographic distribution of the stenohaline or euryhaline marine molluscan taxa and their presence in different marine zoogeographic provinces were analyzed. Special emphasis was set on the search for benthic stenothermic warm-water species because they can be considered useful climatic indicators (Valentine, 1958): bivalves and gastropods whose present geographic ranges are temperature-limited, mainly controlled by tropical or subtropical water masses (Fig. 3).

It was assumed that the molluscs inhabiting mid Holocene seas lived in distinct faunal provinces as they do today (Beu, 1975) and that the same environmental factors controlling them at present acted in the past.

The palaeoenvironmental reconstruction is supported by a global faunistic analysis based on very abundant material and especially on the systematic revision of the bivalve taxa (Aguirre, 1988).

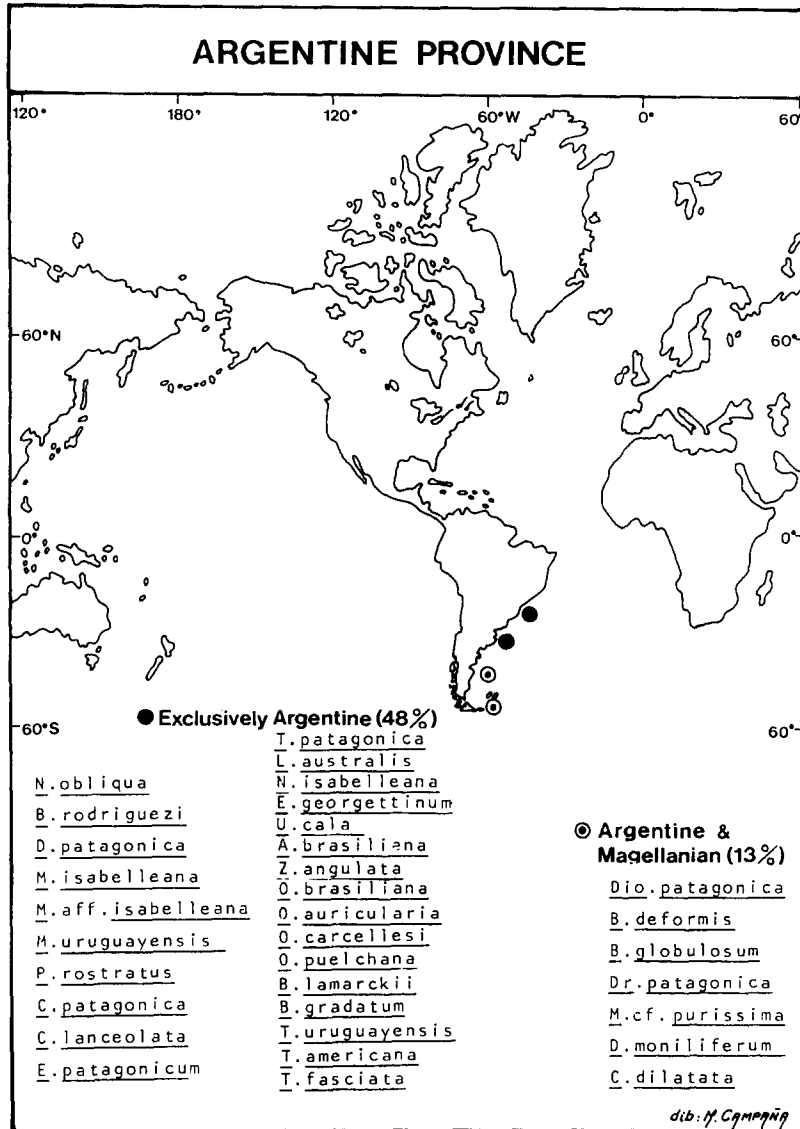


Fig. 3. Present distributional patterns in the Argentine Province of the molluscs recorded in beach ridges of the Las Escobas Formation.

Factors controlling present macrobenthic zonation and geographic distribution of the molluscan species studied

Several environmental factors control the modern marine distribution of benthic molluscs: temperature of water masses, oceanic currents, substrate type, salinity, depth, oxygen and food supply, among others. The last two parameters cannot be evaluated and contrasted with the data used here.

Temperature

The distribution of shallow water masses with different temperature ranges strongly influences living molluscan ranges. Several studies were carried out among others by Hall (1964) and Ekman (1967) especially for the Northern Hemisphere, by Ekman (op. cit.) and Boltovskoy (1981) for the Southwestern Atlantic area and by Knox (1960) for the Southern Hemisphere, mainly in the Pacific Ocean. Most of the molluscs collected in the Las

Escobas Fm. are now recorded along the western Atlantic and eastern Pacific, their distribution being defined mainly by minimum temperature rates of shallow water masses.

Along the western Atlantic four categories of shallow water masses were recognized: cold (less than 5°C; \bar{X} = 0°C), temperate (5–15°C; \bar{X} = 10°C), subtropical (15–25°C; \bar{X} = 20°C), and tropical (more than 25°C; \bar{X} = +27°C), named Arctic, Cold, Temperate, Warm-Temperate, and Tropical in the northern hemisphere and Subtropical, Subantarctic and Antarctic in the southern region (Ekman, 1967). For the southwestern Atlantic Boltovskoy (1981) assumed temperatures of 24–30°C for tropical, 18–24°C for subtropical and 3.5–11°C for subantarctic waters. Similarly, along the northeastern Pacific Hall (1964) distinguished five regions based on average temperatures: cold, cold-temperate, mild-temperate (warm-temperate he considered absent or at least not recognized), exterior tropical and interior tropical. Along the southeastern Pacific, from Ecuador to southern Chile, Knox (1960) recognized warm-temperate, cold-temperate and cold shallow regions (see also Briggs, 1974).

On the other hand, the distributional patterns of the molluscs studied here (Figs. 3, 4, 5) are concerned mainly with the following zoogeographic provinces: (in the Atlantic from North to South America) Virginian (temperate), Carolinian (subtropical), Caribbean (tropical), Antillian (tropical), Brazilian (subtropical), Argentinian (warm-temperate or temperate; from 30–32°S to 40–44°S, see Carcelles, 1944) and Magellanian (cold; southwards from 44°S); (along the eastern Pacific from North to South America) Californian (exterior tropical), Panamic (interior tropical), Galapagos region (tropical), Peru-Chilean (temperate), Central-Chilean or Argentinian (temperate to cold-temperate) and Magellanian (cold) (see Knox, 1960; Ekman, 1967; Briggs, 1974).

Depth

It is well known that depth and temperature are strongly related environmental factors. A clear zonation of the molluscan associations inhabiting supralittoral to infralittoral depths have been

observed along several western South Atlantic littoral areas (in relation to this study see Olivier et al., 1966, 1968, 1972; Scarabino et al., 1975; Scarabino, 1977; Bemvenuti et al., 1978; Layerle and Scarabino, 1984; Roux et al., 1988).

Along the shallow littoral of Buenos Aires Province, nearer to the coast, approximately down to 80 m, a typical Antillian molluscan fauna is recorded at present; then a transitional fauna composed of many endemic Argentine elements is recognized, whilst deeper (more than 100 m) a Magellanian set is found (see Carcelles, 1944; Castellanos, 1967).

On the other hand, water energy, another factor related to depth (and substrate), although changing locally, should be expected to have been greater in shallower areas with harder substrates (i.e., loc. 2 and 3 of this study).

Currents

Considering the world oceanic shallow circulation pattern and the extent of shallow water masses it is evident that the western Atlantic is hydrographically dominated mostly by warm-water currents (Knox, 1960; Ekman, 1967; Valentine, 1973). The main warm currents are: (for the northern hemisphere) the North Equatorial or Antillian, the Guayanan and the Gulf Stream Currents; (for the southern) the South Equatorial and the Brazilian (see also Briggs, 1974; Boltovskoy, 1981). Along the Pacific the most important are the South Equatorial, the North Equatorial and the California Currents.

Along the continental shelf of Argentina the map of shallow isotherm distributions (see De Aparicio and Difrieri, 1958) shows the influence of the cool Malvinas Current towards the north and of the warm Brazilian Current to the south. But most of the Argentine oceanic littoral is stronger affected at present by the cool Malvinas Current and the Subantarctic water mass. This current flows between the continent and the more external Brazilian Current, whilst the latter flows away from the coast southwards and has little influence on the coastal area.

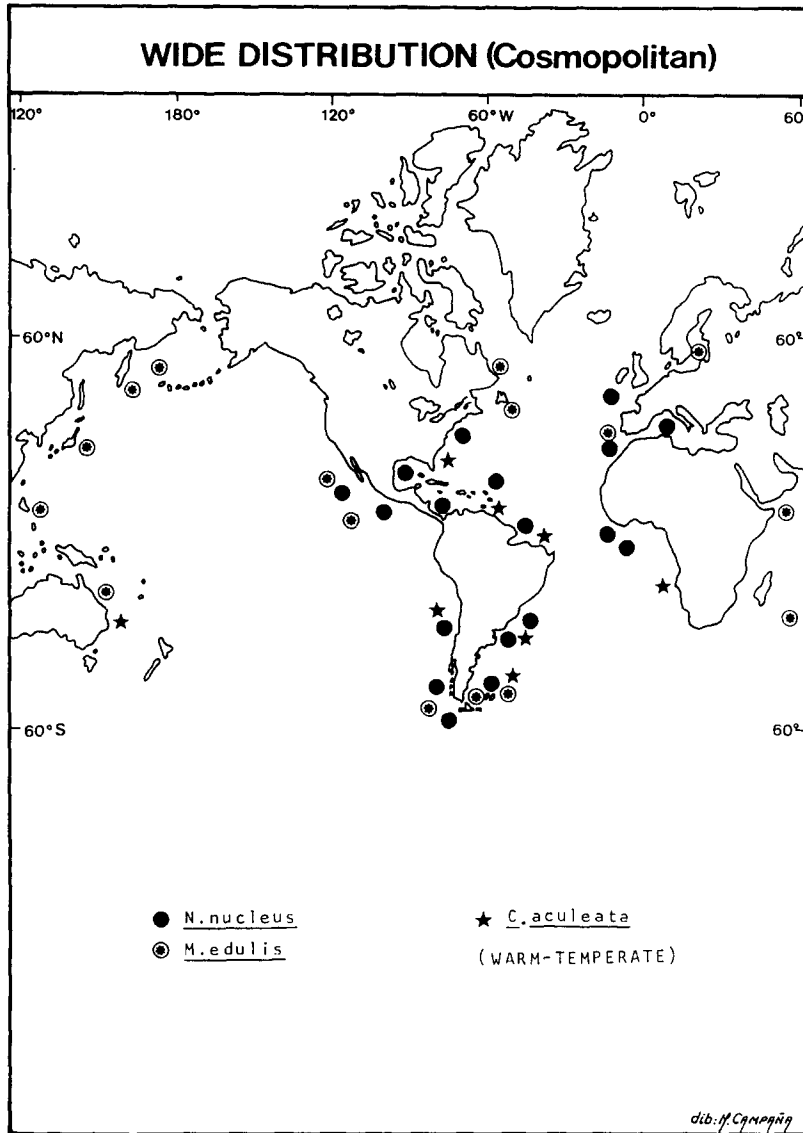


Fig. 4. Present worldwide distributional patterns of the molluscs recorded in beach ridges of the Las Escobas Formation.

Substrate

Substrate is one of the main controlling factors for benthic communities. Important correlations have been established between the nature of the bottom and the molluscan associations developed over or inside. Substrate is clearly one of the main controlling factors of benthic communities (Allen, 1954; Thorson, 1957; Elias, 1985; Bremec, 1986; Roux et al., 1988).

Unfortunately, a detailed pattern of sediment

distribution related to the living molluscan associations is not available for the whole area of study. However, localized ecological or biocoenological studies concerning substrate type in surrounding littoral areas are: those of Capitoli et al. (1978) and Bemvenuti et al. (1978) in southern Brazil; Escofet et al. (1979), Cachés (1980) and Layerle and Scarabino (1984) for the Uruguayan coastal area and Olivier et al. (1966, 1968, 1972), Bastida et al. (1981) and Roux et al. (1988) for the area of Mar del Plata; Elias (1985, 1987) and

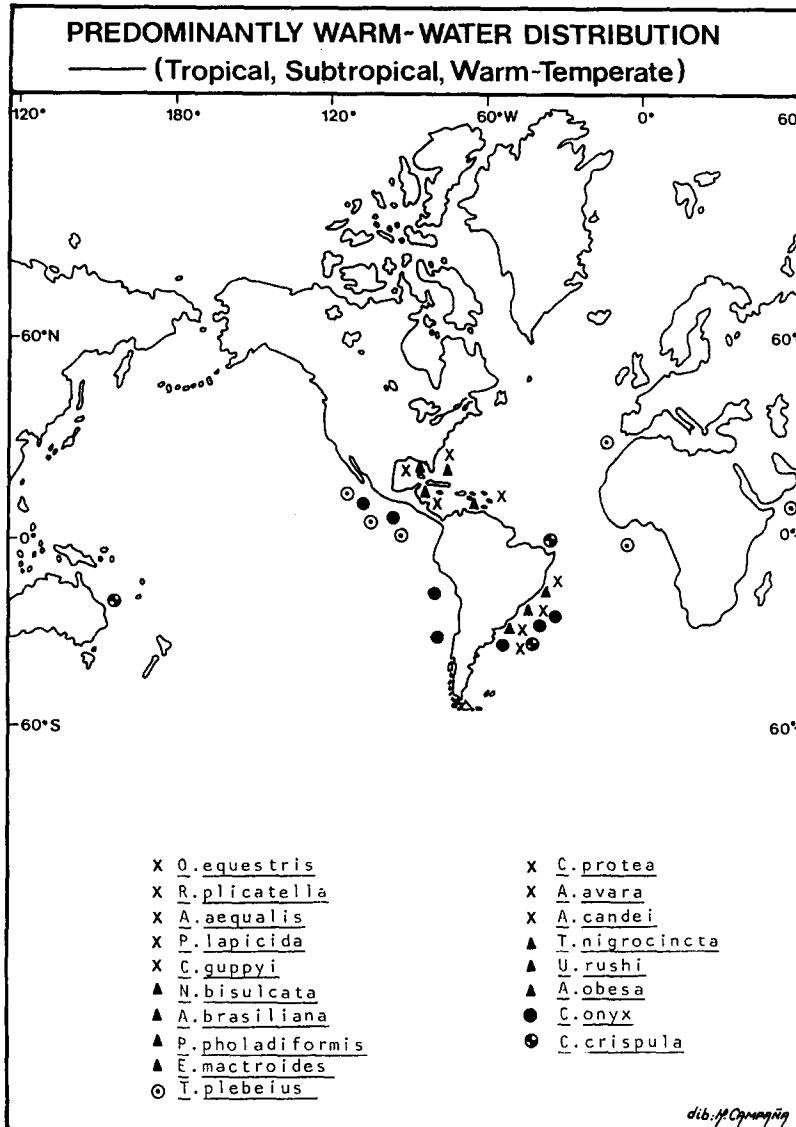


Fig. 5. Present, predominantly warm-water, distributional patterns of the molluscs recorded in beach ridges of the Las Escobas Formation.

Bremec (1986, 1987, 1989) for the Bahía Blanca area.

Salinity

The expected local variations (i.e. M. Chiquita coastal area) for the oceanic littoral occur along the area of study, i.e, an euhaline salinity range.

Along the southwestern Atlantic Boltovskoy (1981) assumed salinities of 34.5‰–38.8‰ for the Argentinian Malacological Province, more than

36‰ for subtropical and “tropical” areas of the Brazilian and Antillian Provinces and 34–34.5‰ for subantarctic waters of the Magellanian region while Knox (1960) considered a salinity fluctuating between 33 and 35‰ for the shallow warm-temperate water mass and Olivier et al. (1966) registered values of 33–35‰ off Mar del Plata, Buenos Aires Province. Thus, most of the marine fauna from the area is assumed to live mainly within a salinity range of ca. 33 and 38.8‰.

Oxygen and food supply

As Boucot and Carney (1981) pointed out, oxygen availability is a factor that cannot be easily analysed by the paleontologist. Nor is the food supply easily analysed. With no data provided by the fossils studied here these two parameters have not been considered.

A few data on the biologic productivity of the southwestern Atlantic, a factor which is directly correlated with the former, can be obtained from Boltovskoy (1981, p. 241).

Regional marine hydroclimate

Hall (1964) established that the limiting factor determining the boundaries of marine climates is the number of consecutive days or months during which normal marine water is subject to those temperatures needed for the reproduction and early growth of the organisms. This factor is determined by the geographic latitude, continental and oceanic configuration and oceanic currents and is revealed by animal distribution.

Except for the atlas of Boltovskoy (1981) discussing several physical and biological factors controlling the planktonic organisms distribution (based mainly on foraminiferids) in the area, no such studies have been achieved for the molluscan faunas of southwestern Atlantic.

Results

Molluscan occurrences and general faunal composition

The composition and distribution of the molluscan fauna from the beach-ridges is synthesized on Table 2 taking into account the main sectors within the area of study: Berisso (loc. 1), P. Indio (loc. 2, 3), P. Piedras (loc. 4) and Samborombón Bay (loc. 5–13) (Fig. 2).

A total of at least 63 mega-invertebrate taxa were discriminated. Molluscs are the dominant elements (97%); gastropods (35 species) outnumber bivalves (23 species) both in species richness and density. Low percentages of polyplacophorans, polychaetes, cirripedes (balanids), scle-

ractinid corals, brachyuran dactylae and an abundant microfauna (ostracods, foraminifers and micromolluscs) constitute the associated elements.

Practically all the molluscan species still live in the surrounding littoral, either along the oceanic coast between P. Rasa and M. del Plata or in the adjacent mixohaline and poly-euhaline Río de La Plata area. This fact facilitates the palaeoenvironment reconstruction as all the species provide useful and reliable ecological data for the interpretation of the original habitat (see also Hall, 1960) (Table 3 a,b).

There are a few dominant taxa, mixohaline (i.e. *Littoridina australis*) or poly-euhaline (*Mactra isabelleana*), whereas the majority of the molluscs are very scarcely represented stenohaline marine or euryhaline species (Aguirre, in press). The dominant, autochthonous, species indicate a mixed original environment with a salinity range fluctuating between mixohaline (8–18‰; loc. 12, 13) and polyhaline (18–30‰; loc. 1, 4–9) or poly-euhaline (+30‰; loc. 2, 3‰) (Aguirre, 1990, 1991a).

The whole fauna constitutes a fossil assemblage consisting of three main elements: (1) an epifaunal gastropod element; (2) a sandy infaunal element (bivalves); and (3) a hard-substrate element (gastropods and bivalves) (Table 4; see also Addicott, 1966). This suggests that two kinds of substrates were present originally in the neighbourhood of the fossil localities: a hard, rocky substratum (i.e., loc. 2, 3) for epifauna and borers, and a sandy bottom for the infauna and some epifaunal elements (i.e., loc. 7, 10).

Most of the species range from the intertidal down to the infralittoral zone. The frequencies of the species characterizing each biofacies in the area (see Aguirre, 1991a) lead one to assume that the original communities must have lived in shallow water, mainly in the upper infralittoral zone down to 50–60 m depth. However, most of the taxa from loc. 2 and 3 might have lived in shallower associations of the intertidal and supralittoral zones (Tables 3 and 4).

The molluscan fauna from Las Escobas may have inhabited mainly shallow littoral (especially inner shelf) benthic original habitats (Table 4). It could be assumed that they did not live deeper than 50–80 m (Table 3a, b). This is also confirmed

by data about the living molluscs sampled by oceanographic campaigns along the Argentinian continental shelf (see also Aguirre, 1990b; Bastida et al., 1981; Roux et al., 1988). On this basis, the whole fauna could belong to an original shallow water environment and so might have been controlled by superficial currents and isotherms down to 100 m below the surface (Ekman, 1967, p. 58).

Preservation

These shelly accumulations represent taphocoenoses where the fossils were transported different distances from their original environment and reworked. The fossils show in general a “near-modern” aspect due to their Holocene age. Although the preservation of the shells is in general good, it varies between the different beds. The high percentage (ca. 50%) of broken valves, mainly relatively big, sharp-edged fragments of *Mactra isabelleana* (13 mm long on the average), little eroded, with mostly well-preserved surface sculpture, suggest a high-energy depositional environment and considerable transport along an extensive beach zone (Aguirre, 1990, 1991a). Together with this, the abundance or dominance of infralittoral taxa (i.e. *Mactra isabelleana*) in accumulations most probably originated along the intertidal zone (see Frenguelli, 1957; Fidalgo et al., 1973; Reineck-Singh, 1980; Spalletti et al., 1987) or supratidal zone (Ortlieb et al., 1989; Diaz and Ortlieb, 1992) is another indication of transport of the valves from a deeper original habitat.

A few articulated specimens of *Mactra isabelleana* lying parallel to the bedding plane were found in a few levels at loc. 7. They must have been washed out from their original position because this bivalve lives with its commissural plane at approximately 30–35° from the vertical. Except for those shells, in no other bed or locality have other bivalves been found with their valves joined, retaining their ligament or remaining in their living position.

On the other hand, there is no evidence of a marked mixing of elements from different communities, they are all molluscan representatives of an original benthic community.

Distributional patterns of the molluscan species from the Las Escobas Formation

In order to attempt a palaeoclimatic and palaeobiogeographic reconstruction of the study area, data on the stratigraphic and geographic ranges of each species and a synthesis of their ecologic requirements are summarized on Tables 2 and 3a,b.

All the molluscs identified have living representatives. Half of the species (10 gastropods and 19 bivalves) are known since the Tertiary (mainly upper Miocene); only 2 range from the Oligocene or Eocene. The remaining taxa (25 gastropods and 4 bivalves) have been recorded exclusively in the Quaternary and 5 of these only in the Holocene. Although it could be considered a “young” fauna, it is likely that future results on the systematic revision of the gastropods would surely define earlier records for many of the species, most probably enlarging the number of pre-Pleistocene species.

In the Las Escobas Formation there is an obvious predominance (practically 60%) of taxa recorded at present in the southwestern Atlantic ocean, a small number of cosmopolitan species (1 gastropod and 2 bivalves) and the rest being found mostly in several zoogeographic provinces along the western Atlantic Ocean or in both the eastern Pacific and the western Atlantic (Table 2). Six of these molluscs show a northwards displacement: they are not known along the oceanic Bonaerensian coasts today, ranging from the Antilles southwards to northeastern Uruguay or southern Brazil. They are: *Noetia bisulcata*, *Anomalocardia brasiliensis*, and *Petricola pholadiformis* (Bivalvia), and *Triphora nigrocincta*, *Anachis obesa* and *Urosalpinx rushi* (Gastropoda) (Plate 1). *Triphora nigrocincta* had never been mentioned, living or fossil for the Quaternary of Argentina.

Most of this Holocene fauna lives in the present Argentinian Province (18–24°C; Boltovskoy, 1979, 1980) or in different warm-water regions (minimum annual temperatures of 16–24°C) and belongs to the “warm-water unit” (see Ekman, 1967). In addition there are some really tropical elements (species distributed between 20°C isotherms) (Table 4). The distributional patterns of the whole

TABLE 3

Ecologic requirements of the molluscs analysed: 3a, gastropod species; 3b, bivalve species

ECOLOGICAL DATA TAXA GASTROPODA	SALINITY		ZONATION				SUBSTRATE	DEPTH	LIFE HABIT			TROPHIC TYPE					
	Euhaline	Brackish	LITTORAL						Soft	Hard	Clinger addressed	Vagrant	Semi-infaunal	Infaunal	Herbivorous	active passive	Carnivorous
			Supralittoral	Mesolittoral	Infralittoral	Cirralittoral	SUBLI TTORAL										
<i>Diodora patagonica</i>	●		●	●	●	●	●										
<i>Tequila patagonica</i>								10-55									
<i>Littoridina australis</i>	●	●	●	●	●	●	●										
<i>Crepidula aculeata</i>	●		●	●	●	●	●										
<i>Crepidula protea</i>	●		●	●	●	●	●	-120									
<i>Crepidula cf. onyx</i>	●		●	●	●	●	●	20-24									
<i>Crepidula dilatata</i>	●		●	●	●	●	●										
<i>Natica isabelleana</i>	●		●	●	●	●	●	20-72									
<i>Epitonium georgettinum</i>	●		●	●	●	●	●	4+110									
<i>Triphora nigrocincta</i>	●	●	●	●	●	●	●	-120									
<i>Urosalpinx cala</i>	●	●	●	●	●	●	●	-1150									
<i>Urosalpinx rushi</i>	●		●	●	●	●	●										
<i>Zidona anquilata</i>	●		●	●	●	●	●	-175									
<i>Adelomelon brasiliana</i>	●		●	●	●	●	●	20-77									
Volutidae gen et sp. indet.	●		●	●	●	●	●										
<i>Olivancillaria brasiliana</i>	●		●	●	●	●	●	-30									
<i>Olivancillaria auricularia</i>	●		●	●	●	●	●	4-5									
<i>Olivancillaria carcellesi</i>	●		●	●	●	●	●	10-22									
<i>Olivella puelchana</i>	●		●	●	●	●	●	12-63									
<i>Buccinanops lamarckii</i>	●		●	●	●	●	●	5-60									
<i>Buccinanops gradatum</i>	●		●	●	●	●	●	-64									
<i>Buccinanops deformis</i>	●		●	●	●	●	●	10-40									
<i>Buccinanops globulosum</i>	●		●	●	●	●	●	10-20									
<i>Buccinanops</i> sp.	●		●	●	●	●	●										
<i>Dorsanum moniliferum</i>	●		●	●	●	●	●	-40									
<i>Anachis cf. avara</i>	●		●	●	●	●	●										
<i>Anachis cf. obesa</i>	●		●	●	●	●	●	-20									
<i>Drillia patagonica</i>	●		●	●	●	●	●	c. 100									
<i>Mangelia cf. purissima</i>	●		●	●	●	●	●	60-100									
<i>Mangelia</i> sp.	●		●	●	●	●	●										
<i>Turbonilla uruguayensis</i>	●		●	●	●	●	●	6-36									
<i>Turbonilla americana</i>	●		●	●	●	●	●										
<i>Turbonilla fasciata</i>	●		●	●	●	●	●										
<i>Cylichna crispula</i>	●		●	●	●	●	●	50									
<i>Acteocina candei</i>	●		●	●	●	●	●	12-50									

a

fauna, based mainly on the systematic revision of the bivalve taxa and on updated taxonomic discrimination of the gastropods (Aguirre, 1988), is synthesized on Fig. 3-5:

—I: species belonging exclusively to the

Argentinian Zoogeographic Province (48%; 16 gastropods and 10 bivalves) or reaching also down to the Magellanian Province (12%, 7 gastropods) (Fig. 3). They are mainly distributed in warm or warm temperate water masses.

BIVALVIA	ECOLOGICAL DATA		ZONATION			SUBSTRATE	DEPTH	LIFE HABIT			BORROWING INDEX (Stanley, 1970)	TROPHIC TYPE									
	MARINE ESTUARINE	SALINITY	LITTORAL					Cemented	EP1 FAUNA	INFAUNA		Borrowing Index	BORROWING DEPTH	Filter-feeding	Suspension feeder	Impact-feeder	Detritivorous				
			Supralittoral	Mesolittoral	Sublittoral													Endobysate	Shallow deep	Borrower	Endobysate Nestling Borer
<i>Nucula nucleus</i>	●		●	●	●		-2000														
<i>Nucula obliqua</i>	●		●	●	●		-120							●							
<i>Noetia bisulcata</i>	●		●	●	●				●	●	0.1		●								
<i>Mytilus edulis</i>	●		●	●	●		40-50					1.1	●								
<i>B. rodriguezii</i>	●		●	●	●								●								
<i>Ostrea equestris</i>	●		●	●	●								●								
<i>Ostrea cf. equestris</i>	●		●	●	●								●								
<i>Diplodontia patagonica</i>	●		●	●	●		-100						●								
<i>Carditamera guppyi</i>	●		●	●	●		-200						●								
<i>Mactra isabelleana</i>	●		●	●	●		-75				1		●								
<i>M. aff. isabelleana</i>	●		●	●	●								●								
<i>Reeta plicatella</i>	●		●	●	●		4-40						●								
<i>Macoma uruguayensis</i>	●		●	●	●		<1					15-20	●								
<i>Abra aequalis</i>	●		●	●	●		6-2000					25-40	●								
<i>Taqelus plebeius</i>	●		●	●	●						0.4	-30	●								
<i>Pitar rostratus</i>	●		●	●	●		4-160						●								
<i>A. brasiliana</i>	●		●	●	●		40-42				0.3	1	●								
<i>Petricola lapicida</i>	●		●	●	●								●								
<i>P. pholadiformis</i>	●		●	●	●								●								
<i>Corbula patagonica</i>	●		●	●	●								●								
<i>Erodona mactroides</i>	●		●	●	●								●								
<i>C. lanceolata</i>	●		●	●	●								●								
<i>Entodesma patagonicum</i>	●		●	●	●		12-55						●								

REFERENCES: ● Predominantly ↗ Occasionally
 ↘ Microphagous ● Bacteriophagous
 ⊥ Up to < Less Than

b

Table 3 continued.

—II: eurythermic species showing cosmopolitan or wide geographic distribution (5%; 1 gastropod and 2 bivalves) (Fig. 4).

—III: typically warm-water species (tropical, subtropical or warm-temperate masses; 35%, 9 gastropods and 10 bivalves) (Fig. 5). Although this group also shows a wide distribution they are mostly recorded within warm-water areas. They correspond mostly to the Atlantic Caribbean, Antillean, Brazilian and partially Argentine Provinces or they show a worldwide distribution including the Pacific and Indian Oceans. To this group belong the molluscs which are now displaced northwards ("TAMA") (Plate I).

A prior conclusion of this paper is then that most of the fauna from the Las Escobas Fm. (83%) lives today in warm waters (warm-temperate or subtropical = 15–25°C or tropical = +25°C) while a minor component is known either in Subantarctic or Arctic waters (cold-temperate or cold water).

The warm water fauna and the displacement of some molluscan species

The ecological characteristics (Table 3a,b) of the northwardly displaced molluscs indicate similar environmental conditions (substrate, depth, salin-

TABLE 4

Depth and temperature data of the species recorded

T A X A	DEPTH						TEMPERATURE				
	Sp	T	E	M	S	B	Ba	Tr	St	T	Sa
=====											
GASTROPODA:	:	:	:	:	:	:	:	:	:	:	:
3Diodora patagonica	:	*	*	:	:	:	:	:	*	*	*
3Tegula patagonica	:	*	*	*	*	:	:	:	*	*	*
3Littoridina australis	:	*	*	*	?	:	:	:	*	*	*
W3Crepidula aculeata	:	*	*	*	?	:	:	:	*	*	*
W3Crepidula protea	:	*	*	*	*	*	:	:	*	*	*
W3Crepidula cf. onyx	:	:	*	:	:	:	:	:	*	*	*
3Crepidula dilatata	:	:	*	:	:	:	:	:	*	*	*
1Natica isabelleana	:	*	*	*	*	:	:	:	*	*	*
1Epitonium georgettinum	:	*	*	*	*)	:	:	*	*	*
W1Triphora nigrocincta	:	*	*	:	:	:	:	:	*	*	*
1Urosalpinx cala	:	:	*	*	*	*	:	:	*	*	*
W1Urosalpinx rushi	:	:	*	?	:	:	:	:	*	*	*
1Zidona angulata	:	:	*	*	*	*	:	:	*	*	*
1Adelomelon brasiliana	:	:	*	*	*	:	:	:	*	*	*
1Volutidae gen. et sp. indet.	:	:	*	*	*	:	:	:	*	*	*
1Olivancillaria brasiliana	:	:	*	*	:	:	:	:	*	*	*
1Olivancillaria auricularia	:	:	*	:	:	:	:	:	*	*	*
1Olivancillaria carcellesi	:	:	*	*	:	:	:	:	*	*	*
1Olivella puelchana	:	:	*	*	*	:	:	:	*	*	*
1Buccinanops lamarckii	:	:	*	*	*	*	:	:	*	*	*
1Buccinanops gradatum	:	:	*	*	*	:	:	:	*	*	*
1Buccinanops deformis	:	:	*	*	*	:	:	:	*	*	*
1Buccinanops globulosum	:	:	*	*	:	:	:	:	*	*	*
1Buccinanops sp.	:	:	*	*	*	:	:	:	*	*	*
1Dorsanum moniliferum	:	:	*	*	*	:	:	:	*	*	*
W1Anachis avara	:	?	*	*	:	:	:	:	*	*	*
W1Anachis obesa	:	?	*	*	:	:	:	:	*	*	*
1Drillia patagonica	:	:	*	*	*	*	:	:	*	*	*
1Mangelia cf. purissima	:	:	:	*	*	:	:	:	*	*	*
1Mangelia sp.	:	:	:	*	*	*	:	:	*	*	*
1Turbonilla uruguayensis	:	:	*	*	:	:	:	:	*	*	*
1Turbonilla americana	:	:	*	*	:	:	:	:	*	*	*
1Turbonilla fasciata	:	:	*	*	*	:	:	:	*	*	*
W1Cylichna crispula	:	:	*	*	*	:	:	:	*	*	*
W1Actaeocina candei	:	:	*	*	:	:	:	:	*	*	*
BIVALVIA:											
2Nucula nucleus	:	:	*	*	*	*	*	:	*	*	*
2Nucula obliqua	:	:	*	*	*	:	:	:	*	*	*
W3Noetia bisulcata	:	:	*	*	?	:	:	:	*	*	*
3Mytilus edulis	:)	*	*	*	:	:	:	*	*	*
3Brachidontes rodriguezi	:	*	*	*	:	:	:	:	*	*	*
W3Ostrea equestris	:	:	*	*	?	:	:	:	*	*	*
3Ostrea cf. equestris	:	:	*	:	:	:	:	:	*	*	*
2Diplodonta patagonica	:	:	*	*	*	:	:	:	*	*	*
W32Carditamera guppyi	:	:	*	*	*	*	:	:	*	*	*
2Mactra isabelleana	:	:	*	*	*	:	:	:	*	*	*
2Mactra aff. isabelleana	:	:	*	*	*	:	:	:	*	*	*
W2Raeta plicatella	:	:	*	*	*	:	:	:	*	*	*
2Macoma uruguayensis	:	:	*	:	:	:	:	:	*	*	*
W2Abra aequalis	:	:	*	*	*	*	*	:	*	*	*
W2Tagelus plebeius	:	:	*	*	:	:	:	:	*	*	*
2Pitar rostratus	:	:	*	*	*	*	:	:	*	*	*
W2Anomalocardia brasiliana	:	:	*	*	*	:	:	:	*	*	*
W3Petricola lapicida	:	:	*	*	:	:	:	:	*	*	*
W3Petricola pholadiformis	:	:	*	:	:	:	:	:	*	*	*
2Corbula patagonica	:	:	*	*	:	:	:	:	*	*	*
W2Erodona mactroides	:	:	*	*	:	:	:	:	*	*	*
3Cyrtopleura lanceolata	:	:	*	*	:	:	:	:	*	*	*
2Entodesma patagonicum	:	:	*	*	:	:	:	:	*	*	*

REFERENCES:

- 1: Epifaunal
 2: sandy infaunal
 3: hard substrate
 W: warm-water indicator

DEPTH: The bathymetrical vertical division was partially taken from a pattern of Kanazawa (1990):

- Sp: supralittoral
T: tidal (intertidal) zone
E: euneritic zone (low tide mark to 20-30m deep)
M: mesoneritic zone (from 20-30m to 50-60m)
S: subneritic zone (50-60m to 100-120m)
B: bathymetric zone (100-120m to 250m)
Ba: bathyal zone (1000-2000m)
l: occasionally

TEMPERATURE: Geographic regions of shallow modern oceanic waters (ranges taken from Ekman, 1967 and Boltovskoy, 1981):

- Tr: tropical (+ 25 C; X= 27 C)
St: subtropical (15-25 C; X= 20 C)
T: Temperate (5-15 C; X= 10 C)
Sa: Subantarctic = Cold (- 5 C; X= 0 C)

Table 4 continued.

ity, life habits and trophic types) with those of the remaining taxa of the Las Escobas Formation. They may have had similar or identical requirements as those species living nowadays along the Buenos Aires coastal area and also down to Golfo San Matías (ca. 42-43°S) (Argentine Province). The following still need investigation: (1) are they certainly absent along the oceanic Argentine littoral today; is the absence just a consequence of incomplete sampling or a chance absence, (2) why did these species live southerly during the mid Holocene ?, (3) could this situation be a consequence of environmental changes, an indication of different climatic conditions during the late Quaternary in the area ?

This set of small molluscs cannot have been overlooked due to their small size (i.e. *Triphora nigrocincta*, *Anachis obesa*, *Petricola pholadiformis*) since similar small-size taxa (even of the same genus) have been described or figured from the Argentine Sea, especially from the Bonaerensian coastal area (see Carcelles, 1944; Camacho, 1966; Castellanos, 1967; or mentioned by Elías, 1985, 1987 and Bremec, 1986, 1989).

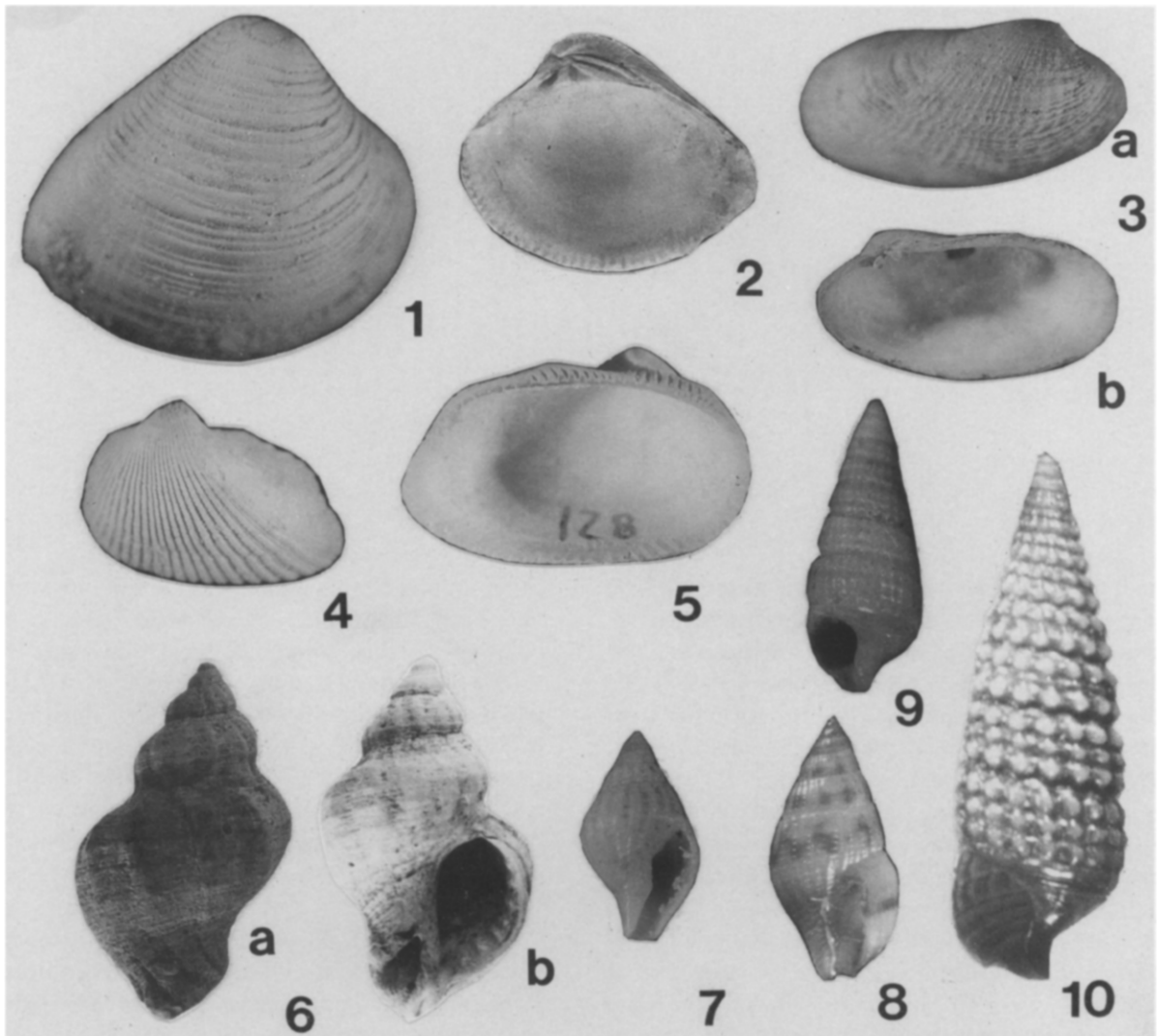
It could be suspected that they are present deeper offshore in the neighbouring littoral, where the remaining taxa are found, or that they live in shallower waters. In order to find out their eventual distribution within the neighbouring benthonic

communities, a comparison was carried out to the greatest detail possible between the fossil assemblages from the Holocene beach-ridges and the living associations along the continental shelf (mostly from southern Brazil and Uruguay down to Mar del Plata and Bahía Blanca; see Aguirre, 1990a, in press).

Comparison between the fossil assemblages and the living molluscan communities

The absence of the mentioned species along the Bonaerensian oceanic coastal area has been documented through updated knowledge of the molluscan records along the continental shelf between southern Uruguay and Golfo San Matías, and not merely through the comparison of catalog taxonomic lists. However, quantitative data on the living associations, similar to those obtained here for the Holocene fossil assemblages, are not available for the oceanic littoral in the area.

The information was gathered by examining samples taken by oceanographic campaigns in the area (mainly fishery expeditions) in the area ("Shinkai-Marú", "Canepa", "Mar del Plata", "Walter Herwig") and from the bibliographic data of other expeditions: Layerle and Scarabino (1984) off the Uruguayan and Bonaerensian coasts, Scarabino (1977) off Golfo San Matías and Roux



“Northwards”-displaced species (“TAMA”).

- 1–2. *Anomalocardia brasiliiana* (Gmelin, 1791). 1, exterior view of the right valve, $\times 2$. Holocene of the area of P. Indio (MLP 1902/1). 2, interior view of the right valve, $\times 2$. Holocene of La Plata (MLP 1901/2).
3. *Petricola pholadiformis* Lamk., 1818. Holocene of P. Indio area, $\times 4$ (MLP 25940). 3a, exterior view of the right valve. 3b, interior view of the same valve.
- 4–5. *Noetia bisulcata* (Lamk., 1819). 4, exterior view of the left valve, $\times 2.5$. Holocene of Samborombón Bay (MLP 25980). 5, interior view of the left valve, $\times 2.5$. Holocene of P. Indio area (MLP 25978).
6. *Urosalpinx rushi* Pilsbry, 1897. Holocene of P. Indio area (MLP 1392/2), $\times 2$. 6a, exterior abapertural view. 6b, exterior apertural view.
- 7–8. *Anachis obesa* (C.B. Adams, 1845). 7, exterior apertural view, $\times 8$. Holocene of P. Indio (MLP 25977). 8, Paralectotype. Exterior apertural view (Museum of Comparative Zoology of Harvard, MCZ N° 186152), approximately $\times 7$.
- 9–10. *Triphora nigrocincta* (C.B. Adams, 1839). 9, exterior apertural view, $\times 8$. Holocene of P. Indio area (MLP 25934). 10, Lectotype. Exterior apertural view (MCZ N° 186157).

et al. (1988) along the Argentine shelf off Mar del Plata. The sample stations include the littoral area striking between 9–130 m (infralittoral to circalittoral zones). To cover the shallower littoral, supplementary data were compiled by means of a collection carried out in 13 localities between P. Rasa and southwards of M. del Plata surroundings, including the supralittoral, intertidal and the shallowest infralittoral (Aguirre, 1991a). Ecologic and biocenologic studies made in the area were also taken into account. Thus, the chance that these species are absent as a consequence of their small size, inadequate sampling or differential habitats and habits could be set aside with a high degree of confidence.

Another interesting comparison deals with the abundance of the stenothermic warm-water taxa (those showing mainly or exclusively tropical and subtropical geographic ranges; Fig. 5) during the mid Holocene (Las Escobas) and at present (Fig. 6). An extension of this comparison to the coastal area of southern Brazil, Uruguay and Mar del Plata and Bahía Blanca in Argentina, reinforce the observations mentioned above (see Gofferjé, 1950; Buckup and Buckup, 1957; Sprechmann, 1978; Ríos, 1985; Bremec, 1987).

While approximately 35% of the molluscs show a “warm-water” character in the Las Escobas Formation, southwards in the Mar Chiquita area the same Holocene ridges show only 19–21% of this fauna, decreasing southerly in similar deposits of Bahía Blanca (approximately 12%; see Farinati, 1985). On the other hand, only 6% of this fauna is found at present in the shallow continental shelf (20–100 m) between Argentina and Uruguay; 3–4% in the Uruguayan littoral area (infralittoral and circalittoral, 9–78 m) and 2–3% off Mar del Plata (mainly circalittoral and also infralittoral zones). Between P. Rasa and Mar del Plata, at much shallower depths, 14% of the living molluscs are warm-water species. Finally, for the whole Argentine zoogeographic province Carcelles (1944) assumed that 29% of the living molluscs are of Antillian origin (see also Sprechmann, 1978).

All these comparisons lead one to conclude that:

(1) the absence of the “displaced” species is confirmed both in the shallow littoral area and in the external shelf (oceanic) region.

(2) the dominant species (brackish or euryaline marine) in the beach-ridges represent a minor component in the living associations recorded in the adjacent continental shelf today or they are absent in the ocean; inversely, the species scarcely represented in the ridges (stenohaline marine) undoubtedly occur in the ocean, but generally with higher frequencies.

(3) a “warmer character” of the molluscs from Las Escobas is assumed.

Climatic and paleobiogeographic implications

A latitudinally decreasing trend in the abundance of the stenothermic warm-water elements is observed both during mid Holocene times and at present (Fig. 6), but these warmer elements were evidently more abundant during the deposition of the Las Escobas Formation. It is quite probable that the subtropical shallow water mass had a slightly southerly extension ca. 6000–5000 ¹⁴C yr B.P. A probable explanation for this situation could be sought in relation to the very rapid late Quaternary coastal evolution in the area (Codignotto and Aguirre, 1993).

Approximately 7000–6000 ¹⁴C yr B.P., with the maximum transgressive phase of the Holocene, the shoreline outline was placed westwards with a maximum extension (ca. 20–30 km) landwards on the continent in the Salado Basin and Grl. Lavalle areas (see Fidalgo, 1979; Fidalgo and Tonni, 1978; Codignotto and Aguirre, 1993). Thus, the Brazil Current should have extended more southerly and westerly than at present having a greater influence than today off southeastern Brazil (i.e. down to the Río Grande do Sul coastal area). The southern limit of the Brazil Current and, as a consequence, of the Argentinian zoogeographic province, must have as well been located southwards, reaching at least the vicinity of Puerto Quequén (ca. 38.5°S) or Bahía Blanca (ca. 39°S).

At present the Brazilian current (from Cabo Frio, Brazil, ca. 23°S, to Golfo San Matías, ca. 43°S) meets the Malvinas Current (from Tierra del Fuego to Río de La Plata) immediately seawards of the Río de La Plata estuary giving rise to the subtropical-subantarctic convergence (between 30–47°S in winter and 34–49°S in summer;

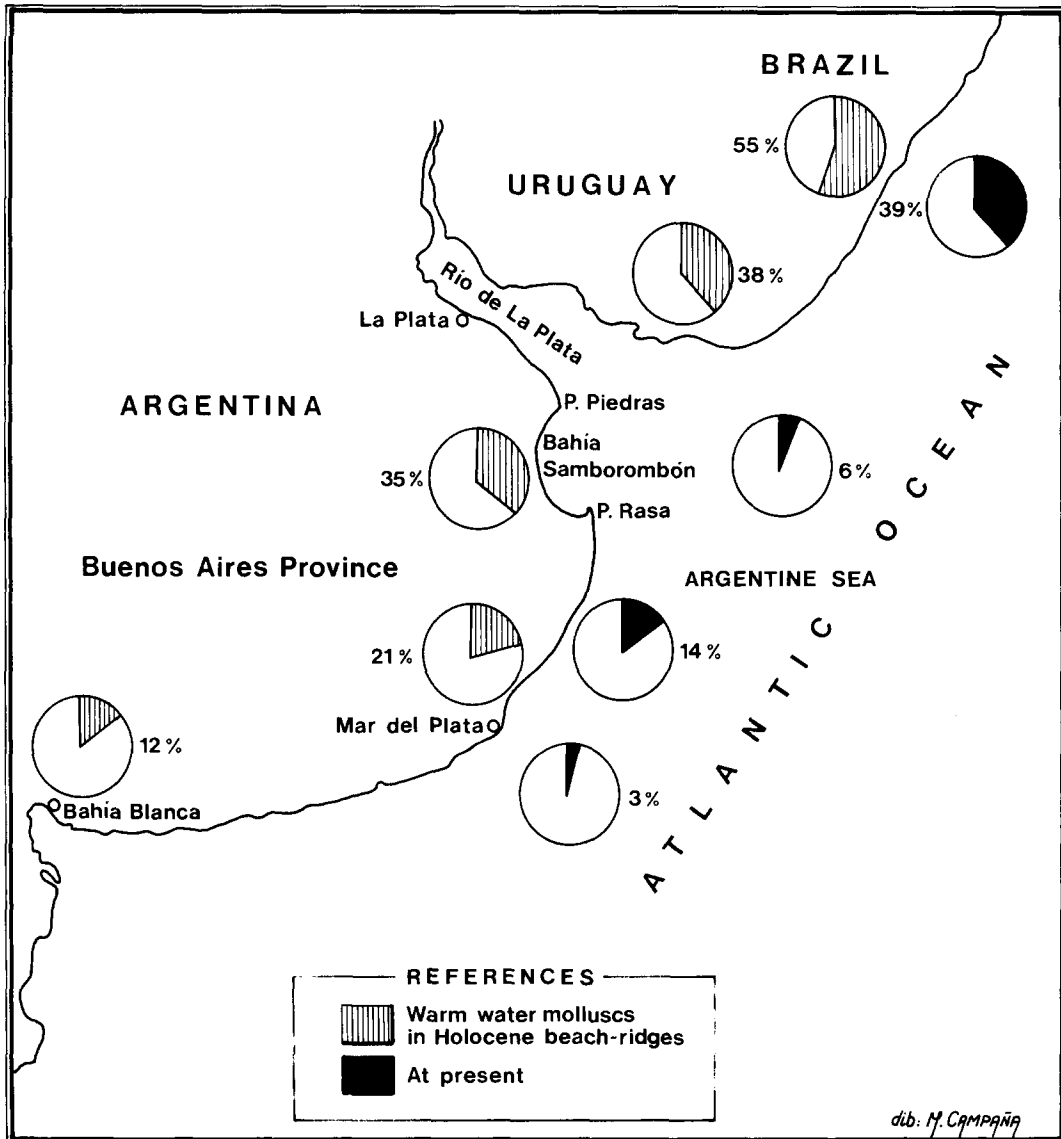


Fig. 6. Quantitative comparison of warm-water molluscs from the Holocene beach-ridges and the recent oceanic littoral. References: 6% correspond to 20–100 m depth; 3% to 38–130 m; 14% to the supralittoral and upper infralittoral zones.

Boltovskoy, 1981) and the transitional character of the marine fauna of the area. Additionally, there is a change in the direction of the prevailing winds at this latitude (ca. 34–35°S), so that the Brazil Current flows away eastwards from the coast (Briggs, 1974, p. 142).

After the maximum of the Holocene transgression the following minor sea-level falls and rises provoked a progressively easterly displacement of the palaeocoasts to reach the present coastline

configuration, with the smaller Brazilian influence on the Buenos Aires littoral area, now more affected by the Malvinas Current.

The Las Escobas Formation corresponds to the last Quaternary marine transgression, slightly later than the glacial melting resulting from a global temperature increase. After the maximum transgressive phase the lower temperature postulated for Postglacial times and eventually different prevailing winds must have determined minor fluctu-

ations of the warm current and progressively cooler waters in the area. Since then, a restriction or latitudinal displacement of the tropical and subtropical water masses must have taken place along the Argentinian continental shelf as a consequence of the paulatine water cooling. Evidently, there must have been a shift of the superficial marine isotherms along the western South Atlantic (see also Boltovskoy, 1979).

The marine molluscan evidence presented here can be added to other data on synchronous continental sediments and vertebrate faunas from the same area indicating that the Las Escobas could be correlated with warmer and humid conditions and that it was deposited during the Hypsithermal (or part of it) (Fidalgo, 1979; Fidalgo et al., 1990).

On the other hand, based on presence-absence molluscan data of Pleistocene and Holocene marine deposits along the Pacific coastal area in northern Perú, other authors (Ortlieb et al., 1989a,b, 1990; Diaz and Ortlieb, 1991, 1992; De Vries and Wells, 1990 among others) assumed that these types of molluscan displacements more probably respond there to storm events or palaeoceanographic anomalies like the known "palaeo-ENSO" records (El Niño southern oscillations) than to climatic changes.

Discussion

During at least part of the deposition of the Las Escobas Formation (Cerro de la Gloria Member) a warmer marine hydroclimate must have prevailed. However, this is not indicated by the dominant occurrence of a whole group of fossils. Evidence is based on the presence of six species now northwardly displaced ("TAMA") and on the greater abundance (35% vs. 14–6%) of a set of stenothermic warm-water molluscs (10 bivalves and 9 gastropods) during the late Quaternary (Fig. 3). For this reason, the "higher temperature" could not have been more than a few °C (5–7°C?) and may be equivalent to the shallow water masses characterizing eastern Brazilian coasts, perhaps between 0°S and 20–30°S, at present (likely 18 to 24–30°C) (see also Ringuelet, 1978; Sprechmann, 1978).

The warm-water species occur mostly, as

expected, in the northern localities (P. Indio and P. Piedras; Table 2; mostly loc. 2 and 3; Table 1). Their distribution along the area of study and among the different "rows" of ridges decreases qualitatively and quantitatively with decreasing altitude and distance towards the present coastline. This suggests a gradual drop in the water temperature related to the post-Hypsithermal cooling and the sea level fall trend up to the present (see Mörner, 1984; Newman et al., 1984).

Localities 2 and 3 (P. Indio area) are placed relatively "nearer" to the present shoreline but at a higher altitude (? older) and might be indicative of a warmer invasion within the last ca. 6000 yr B.P., probably equivalent to the 3000 yr B.P. sea level rise of other areas (Urien and Ottmann, 1971 in Boltovskoy, 1979; Martin et al., 1986; Isla et al., 1986; Mörner, 1984; Fidalgo, pers. comm., 1990) after which sea level has been decreasing progressively. The present Samborombón Bay was already outlined by that time, but had a much wider extension (Codignotto and Aguirre, in press). Fidalgo and Tonni (1978) suggested that the maximum of the transgression reached continentward up to Highway Number 2 in the central part of the Samborombón Bay region (see Fig. 2). It is likely that locs. 2 and 3 already conformed to some kind of cape in the area at that time.

Due to the lack of ¹⁴C dating for the localities of P. Indio (except for 4460 and 7600 yr B.P. ages published in 1971 by Cortelezzi and Lerman for deposits in P. Indio surroundings) it becomes difficult to verify if they certainly represent an earlier sea level than the rest (deposits formed during the first transgressive phase of the Holocene) or if they belong to a more modern sea level stand (ca. 3000 yr B.P.). In spite of this gap in our knowledge, it can be stated that locs. 2 and 3 show a very different qualitative and quantitative faunal composition than the remaining ridges of the Las Escobas Fm. and that they contain the highest warm-water molluscan fauna. The subsequent Postglacial cooling (post-Hypsithermal) determined the diminishing or northwards displacement of the warm species. If there has not been an uplift, something which has to be confirmed yet, their higher altitude (Table 1) could be an indication of an older age.

Malacological vs. foraminiferal evidences

The evidence presented here (see also Sprechmann, 1978, for the Uruguayan littoral area) is in disagreement with micropalaeontological data: some general information published by Sprechmann (1978) and Boltovskoy (1979) for the Holocene is not fully coincident with this evidence.

Sprechmann (1978) concluded that the Holocene benthic foraminiferids from the Uruguayan coastal area conform to typical temperate to cold-temperate associations and that their temperatures were similar to the present ones. Based on south-western Atlantic foraminiferal studies from the Miocene to present, Boltovskoy (1979) considered that Holocene temperatures were somewhat lower, but he did not set aside the possibility of a mean annual Holocene temperature somewhat higher than the present as suggested by Sprechmann (1978), assuming that the eventual difference between Holocene and present temperatures would not be significant.

Similar contradictions between molluscan and foraminiferal evidence can be found in the literature for other areas, such as in Kennett (1968) and Beu (1974, 1975). They might be explained by the need for critical systematic revisions of the planktonic foraminiferids on which these inferences are based or because the species used are not really good climatic indicators. On the other hand, Boltovskoy (1979) pointed out that planktonic foraminiferids are better climatic indicators and guides for climatic changes than benthic species, because most of the environmental data of the latter result from transgressive phases which are generally a consequence of interglacial epochs, so obviously warmer than present.

Beu (1975) reinforced the validity of molluscs as better indicators than foraminiferids because the species showing long veliger larval stages (i.e. Neogastropoda, Pectinidae, among others) would change at the same rate to changes in temperature or currents.

The contradiction between malacological vs. microfaunistic results for the Holocene in the study area is still a problem to be solved, perhaps by means of future systematic revisions of the foraminiferids and ostracods not included in this paper.

Conclusions

The mid Holocene marine molluscan assemblages from the coastal area of Buenos Aires Province in Argentina belong to three sets of species, corresponding mostly to three faunal provinces: Argentine (48%), Magellanian (12%) and Brazilian or Antillian (35%). The composition of these assemblages differs from that of the modern shallow water associations in the oceanic littoral (i.e., 3–14% corresponds nowadays to the Antillian group).

The molluscs studied must have lived in distinct faunal provinces as they do today, but the limits of such provinces must have been different between 6000–2500 ¹⁴C yr B.P., to judge from the comparison between fossil and living distributional ranges.

The following may be explanations for this setting:

(1) During the brief time interval of the Holocene between the genesis of the beach-ridges (ca. 6000 ¹⁴C yr B.P.) and the present, glacio-eustatic sea level oscillations, a rapid coastal evolution and minor climatic changes occurred that influenced the composition of the benthic molluscan fauna.

(2) At the time of deposition of the Las Escobas Fm. (Holocene Interglacial) along the coast of the northeastern Buenos Aires Province the marine hydroclimate should have been warmer than the present in the neighbouring Atlantic ocean, although only a slight difference of a few °C may be assumed.

(3) The boundaries for present zoogeographic regions of the Argentine Sea in the southwestern Atlantic must have been defined at higher latitudes. Consequently, the Subtropical–Subantarctic convergence (mixing of the warm Brazilian with the cool Malvinas Currents) could have taken place southwards, not off Río de La Plata (ca. 34–35°S) as today, but probably near Bahía Blanca (c. 39°S). A southward shifting of the marine superficial isotherm through the early and mid Holocene is thus probable.

(4) This palaeobiogeographic pattern might be explained as a result of the greater importance and extension of the Brazil Current flowing along most of the Bonaerensian coastal area, a consequence of the west- and southwards shoreline configura-

tion ca. 7000–6000 ^{14}C yr B.P. and of the temperature increase and sea level rise corresponding to the last Quaternary transgression.

(5) These conclusions support the palaeoclimatic hypothesis of Fidalgo (1979), Fidalgo and Tonni (1978) and Tonni and Fidalgo (1978) assuming that the Las Escobas Formation originated during Hypsithermal times, now supported by our palaeoecologic, palaeoclimatic and palaeobiogeographic analysis of their marine invertebrates.

(6) Among other palaeoenvironmental changes (substrate, salinity, depth) the post Hypsithermal cooling might have determined the differing molluscan composition in the study area at present.

(7) The thermally anomalous molluscan assemblage is likely a consequence of both coastal palaeogeography and a global mid-Holocene climatic change. What distinguished the mid-Holocene Bonaerensian coastal area from the present was its geomorphological stage and also the oceanic shallow water temperature in the area.

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