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Pleistocene marine calcareous macro-and-microfossils of Navarino Island (Chile) as environmental proxies during the last interglacial in southern South America

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ABSTRACT

Macro-and-microfossils, including molluscs, cirripeds, echinoids, foraminifers and ostracods are a significant component of a Pleistocene marine unit located along the southern coast of the Beagle Channel, on Navarino Island, Chile. This paleontological record represents the richest and most diverse macro-and-micro assemblage recovered from Pleistocene southern South America. In total, 97 taxa were identified: 34 molluscs, 57 foraminifers, and 6 ostracods. They comprise a mixture of specimens inhabiting shallow marine environments characterized by strong bottom currents and belonging to different local communities associated with the spatial heterogeneity in this basin. The taxonomic composition of this paleofauna shows remarkable similarities with present-day fauna, indicating that both groups developed under similar environmental conditions. However, slight different climatic conditions at the age of deposition cannot be ruled out. As well, an ecosystem transition towards a truly marine environment with high number of taxa was recognized. Finally, a *Hiatella*-cirriped assemblage deserves special attention since the polymorphic shell of fossil and living *Hiatella* is used as a paleo-environmental tool. In this regard, the small size of *Hiatella* in the studied marine unit is best related to its mode of life as a nestler within empty tests of barnacles, which apparently served as microenvironments for this species. Nevertheless, more geochemical data on living and fossil *Hiatella* shells from the Beagle Channel will be necessary to test the suitability of using this species to evaluate paleo-temperatures and other sea water variations during the Quaternary.

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1. Introduction

Navarino Island is located on the southern coast of the Beagle Channel at the southern tip of South America. This region represents one of the most interesting crossroads in terms of biodiversity and biogeography of the preceding fauna of the present-day biota: it is the continuation of the coast of the American continent, and it is relatively close to Antarctica, although separated by the Scotia Arc.

The marine realm in this area is a complex network of channels, inlets and islands, shaped by glacial and postglacial Quaternary

processes (McCulloch et al., 1997; Bujalesky et al., 2008). At present, the Beagle Channel represents a marine connection between the Atlantic and the Pacific oceans, but during the Pleistocene, the entire basin was repeatedly glaciated at least in two major episodes (Rabassa et al., 2000): the so-called Lennox Glaciation (Middle Pleistocene, Marine Isotope Stage -MIS- 6 or older), and the Moat Glaciation (Late Pleistocene, MIS 4-2), including the Last Glacial Maximum (LGM) which occurred at ca. 25,000 cal. years ago, in correlation with data from the Strait of Magellan (McCulloch et al., 2005). Available evidence in the area strongly suggests that glacial lakes resulting from ice melting were formed about 12,000 ¹⁴C years ago (Heusser, 1989, 1998; Bujalesky et al., 2008). Later, about 8000 ¹⁴C years ago, the area was progressively flooded with marine waters from the open oceans, becoming a marine ecosystem about 7500 ¹⁴C years before present (Rabassa et al., 1986). The Holocene marine transgression is represented with a terrace system (the Beagle Formation; Gordillo, 1993; Rabassa et al., 2000) and raised

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beaches commonly occur along the Beagle Channel coasts. However, Pleistocene raised marine deposits are not well preserved in this region due to the erosive effect of the last glaciation (Rabassa et al., 2000).

In this regard, the new finding of pre-Holocene marine terraces on the southern coast of the Beagle Channel (Rabassa et al., 2008) opens an important window on the paleoclimatic approach and extends the faunal history of the Beagle Channel to the last interglacial period during the Pleistocene. The primary goal of this paper is to provide an overview of this interesting fauna, which represents a unique record for the Quaternary of southern South America. In this temporal framework it is also especially interesting to analyze the colonization process within the Beagle Channel during the Pleistocene taking into account the possibility that this channel acted as a corridor between the Atlantic and the Pacific oceans.

2. General characteristics of the study area

Navarino Island has a surface area of approximately 2800 km², and the studied profile of Corrales Viejos (Fig. 1) is located on its northern coast, east of the town of Puerto Williams. It is part of a wide shelf with a great number of islands and a fjord system across the southern Andes, which at approximately 50° S curve gradually eastwards into Tierra del Fuego.

Navarino Island is part of the Cape Horn Biosphere Reserve and, together with Hoste Island are the southern limits of the Beagle Channel. Along this channel, the shore is characterized by reflective gravel beaches, under a microtidal regime and short period waves initiated by the wind.

The geological history, including the tectonic activity, and resultant sedimentation patterns are responsible for the patchy distribution of rock and sand substrates that alternate along the shore, providing a wide variety of habitats and potential for niche subdivision. The substrate varies in character from mud, silt, sand, shell lags, and rocks.

3. Radiocarbon dates and stable isotopes

3.1. ¹⁴C Ages

At present, two radiocarbon dates obtained by AMS ¹⁴C technique at the NSF-Arizona AMS Laboratory are available for the studied section (Rabassa et al., 2008). They yielded ages of 41,700 ± 1,500 BP (AA 69648; marine shell fragment) and >46,100 BP (AA 75295; *Nothofagus* wood). Rabassa et al. (2008) interpreted that the first date should be considered as a minimum age, whereas the second one (at the resolution limit of the method) should be considered as infinite. The undoubtedly pre-Holocene dated age most probably corresponds to the Last interglacial, or even to an older interglacial of the Mid Pleistocene.

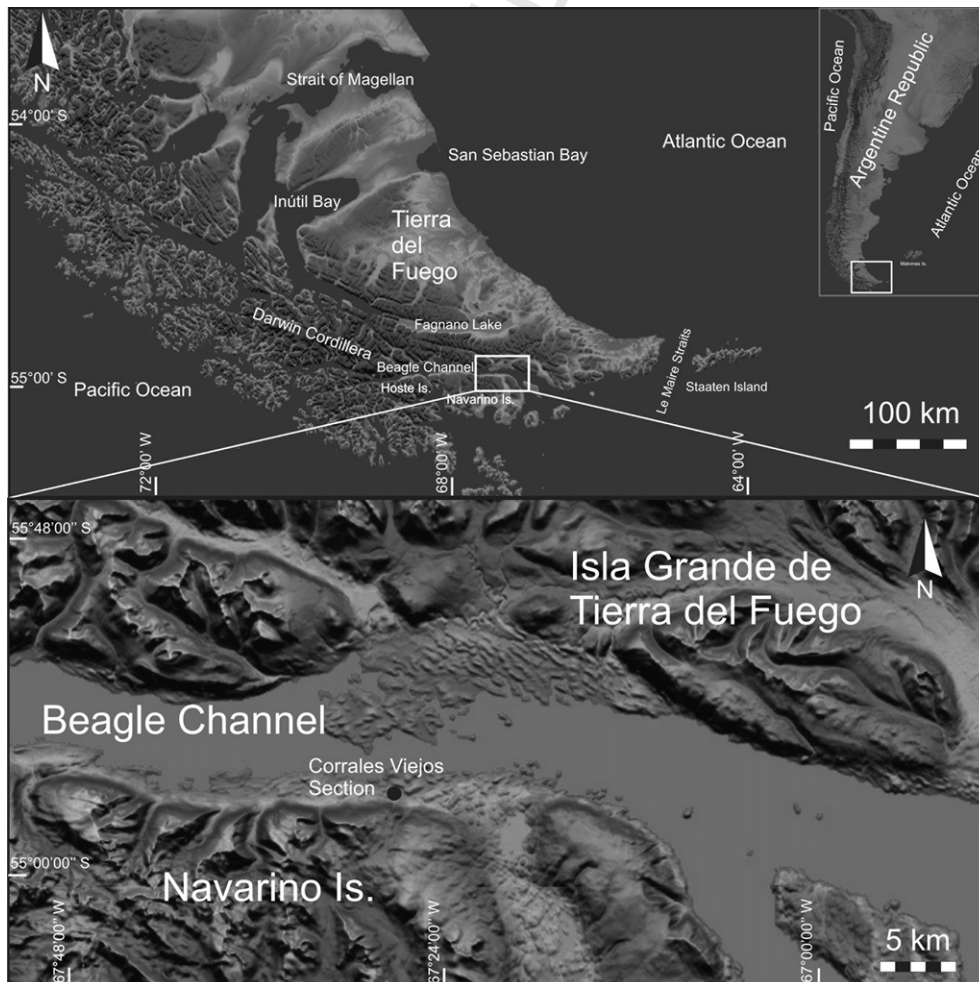


Fig. 1. Map of the study region. Location (upper) and detailed map (lower) of the Corrales Viejos site.

3.2. Oxygen and carbon isotopes as geochemical proxies

Skeletal carbonate oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotopic compositions are often used as geochemical archives of palaeoenvironmental conditions (Wang and Peng, 1990; Brand and McCarthy, 2005, among many others).

Many molluscs precipitate their shells in oxygen isotopic equilibrium with ambient water ($\delta^{18}\text{O}_{\text{w}}$) (Mook and Vogel, 1968). The primary controlling factors of $\delta^{18}\text{O}$ in the carbonate of mollusc shells are the $\delta^{18}\text{O}$ of ambient seawater and ambient water temperature. The $\delta^{18}\text{O}$ of seawater varies as a function of regional variations in river runoff, precipitation and evaporation, and ocean circulation, such as upwelling and surface currents (Goman et al., 2008).

The $\delta^{13}\text{C}$ of mollusc shells primarily reflects the $\delta^{13}\text{C}$ of dissolved inorganic carbon of ambient waters, the carbon isotopic composition of organic carbon consumed by the organism, and kinetic fractionation related to growth rates and calcification (see Goman et al., 2008). Mollusc shell $\delta^{13}\text{C}$ variations are more difficult to interpret than $\delta^{18}\text{O}$ because ^{12}C -rich metabolically derived carbon may be incorporated into shell carbonate, obscuring variations in the carbon isotope composition of water column dissolved inorganic carbon (see references in Takesue and van Geen, 2004). Fossil mollusc shell $\delta^{13}\text{C}$ has also been used to identify past productivity events, since photosynthesis enriches surface waters in ^{13}C relative to ^{12}C (Purton and Brasier, 1997).

In the studied region, isotopic data on modern and fossil shells from the Beagle Channel were previously obtained (see Panarello, 1987; Obelic et al., 1998). Firstly, Panarello (1987) interpreted that Holocene paleotemperatures are more related to local changes and not to a world-wide trend. Obelic et al. (1998) observed that salinity may influence isotopic variations ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of *Mytilus* shells from archaeological shell middens. These authors recognize a cooler period at 6000–5000 ^{14}C BP for the Beagle Channel, as well as a warming period at 4500–4000 ^{14}C BP. The so-called Little Ice Age period from the 15th–19th centuries is also identified by Ortlieb et al. (1998).

4. Paleontological background

4.1. Molluscs

An early mention of fossil molluscs in southern South America was given by Charles Darwin in 1833 during his visit to this region on board the HMS Beagle. However, the first report on Quaternary molluscs from the Beagle Channel was made by R. Hägg (in Halle, 1910), who gave a short list of Holocene taxa collected at Isla Gable. Other mentions of Holocene species were provided by Porter et al. (1984) and Rabassa et al. (1986). Later, Gordillo (1992) carried out a taphonomic analysis of the Holocene molluscs from the Beagle Channel. Additional studies on Holocene molluscs from this area were performed by Gordillo (1993, 1999) and Gordillo et al. (2005).

4.2. Foraminifers and ostracods

The first studies on foraminifers and ostracods date back to the 19th Century with the work of d'Orbigny (1839, in Boltovskoy, 1976), done on littoral material from the Patagonian coast and from the Malvinas-Falkland Islands. Brady (1880) studied the Ostracoda from the oceanographical voyage of H.M.S. Challenger (1873–1876), while his brother (Brady, 1884) investigated the foraminifera of the same area. Both described many species from Tierra del Fuego and the Sub-Antarctic region (Cusminsky and Whatley, 2008).

The study of the ostracoda continued with the German South Polar Expedition (Müller, 1908) and the very important work by

Skogsberg (1928) in the southern South Atlantic and the Sub-Antarctic area. In the latter third of the 20th century this area was the subject of a series of studies on the Ostracoda in the littoral and continental shelf of Southern South America (Whatley and Moguevsky, 1975; Whatley et al., 1987, 1988, 1995, 1996a,b, 1997a,b, 1998; Wood et al., 1999; McKenzie et al., 1995).

Foraminifera studies were followed by Cushman and Parker (1931) and Heron-Allen and Earland (1932) from the Patagonian coast, the Malvinas-Falkland Islands, and Antarctica. In the 1970s, Herb (1971) and Boltovskoy (1976) described the distribution of recent benthic foraminifera in the Drake Passage. Other researchers such as Boltovskoy and Watanabe (1980), Zapata and Alarcón (1988), Hromic and Águila (1993), Hromic (1996, 1999, 2002a, 2009), Hromic and Zúñiga-Rival (2003) and Zúñiga-Rival (2006) analysed the recent foraminifera from Tierra del Fuego and the Strait of Magellan.

5. Material and methods

Sampling was carried out in November 2007 in a marine terrace located at Caleta Pantalón, 10 km west of Puerto Williams, on Navarino Island (54° 56' 08.2" S; 67° 02' 54.7" W; Fig. 1). Bulk samples (about 3 l each) were obtained from two marine levels within a marine bed of 1.12 m thick (Fig. 2, Unit 3), which were identified as "lower" and "upper" levels. Macrofauna was also collected by manual picking at outcrop for rare species or large-bodied specimens. Larger specimens (>20 mm of maximum size) were separated from the sediment matrix in the field and the smaller ones were sorted in the laboratory under a stereoscopic microscope.

Foraminifera and ostracoda were obtained from the lower level (subsamples named as C lower level and S lower level) and the upper level (subsamples C upper level and S upper level). They were first washed with common water, but the last wash was made with distilled water; all foraminifers and ostracods were recovered from 5 g of dry sediment.

The identification and systematics of molluscs is based on several authors: Dell (1971), Linse (1997, 1999), Reid and Osorio (2000) and Cárdenas et al. (2008), among others. For some families recent works were considered: Littorinidae (Williams et al., 2003, Eatoniellidae (Ponder and Worsfold, 1994), Trophonidae (Pastorino, 2005), Nuculidae (Villarroel and Stuardo, 1998), Neoleptonidae (Zelaya and Ituarte, 2004). Molluscs were identified at the lowest taxonomic level possible, but the conservative choice to leave a fair number of taxa at the generic rank is due to the shortage of systematic information covering some modern groups of molluscs of Tierra del Fuego. For example, some families as Buccinidae (genera *Pareuthria*, and *Glypteuthria*) and Pyramidellidae, among gastropods, and Philobryidae, among bivalves, have not been studied in detail.

In foraminifers, the systematic determination at generic level is based on Loeblich and Tappan (1988), whereas the specific level was determined according to Herb (1971), Boltovskoy and Watanabe (1980), Boltovskoy et al. (1980), Cusminsky (1992), Hromic (1996, 2002a), Hromic and Águila (1993) and Hromic et al. (2006), among others.

The determination of ostracods is based on Moore and Pitrat (1961) and van Morkhoven (1963), at the generic level; Whatley et al. (1987, 1988, 1995, 1996a,b, 1997a,b, 1998) and Whatley and Cusminsky (2002) were used to specific level.

Molluscs were identified using a binocular microscope (LEICA MZ) and digital photography or a SEM-scanning electron microscope (LEO 1450VP) and were deposited at the Centro de Investigaciones Paleobiológicas, Universidad Nacional de Córdoba (CEGH-UNC). With respect to foraminifers and ostracods, the most

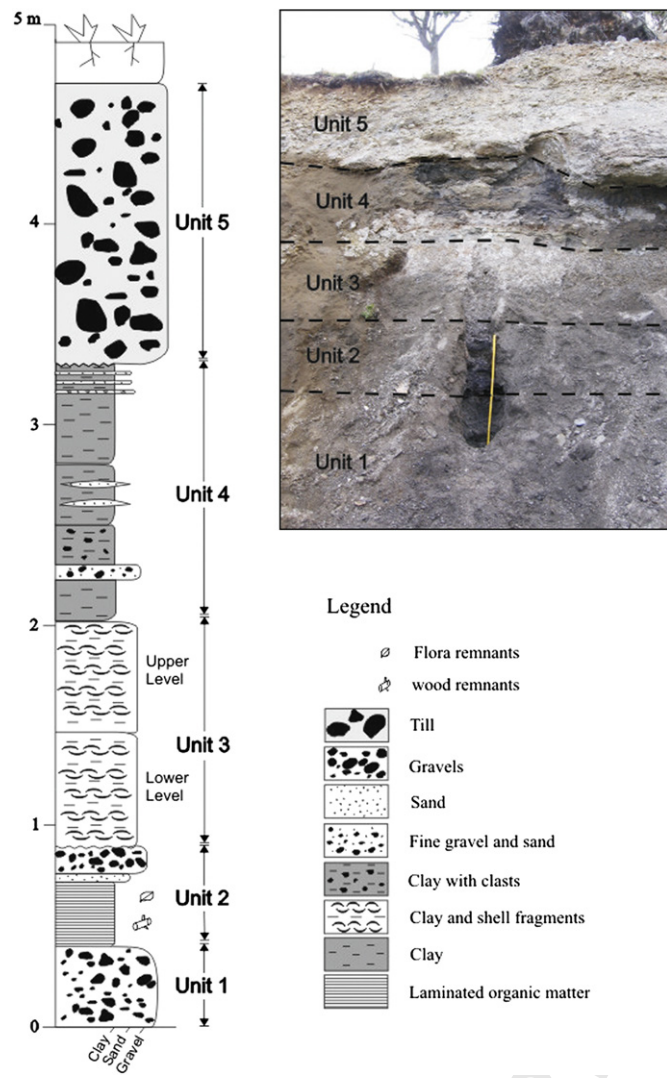


Fig. 2. Stratigraphic section at Corrales Viejos site, showing five main stratigraphic units (Units 1–5). The calcareous macro-and-micro fauna studied was recovered from the lower and upper levels of the marine layer (Unit 3).

representative specimens were also photographed with a SEM (Philips SEM 515) of the Centro Atómico Bariloche, and were stored at the repository in the Museo de Ciencias Naturales, Universidad de La Plata (MLP-Mi).

In molluscs, the ecological characterization is based on the available data on modern benthic organisms from the Magellan region. Some features of the mollusc assemblage (as ratio of opposite valves, fragmentation, abrasion, bioerosion and encrustation) were also considered in order to reconstruct paleoenvironment conditions and the post-mortem processes affecting macrofossils. Specimens were counted, but in the case of highly fragmented remains and colonial organisms (i.e. cirripeds), we recorded the presence of species/taxa in the sample. To evaluate the variability of size and shape of the bivalve *Hiattella* collected in the mollusc assemblage, 40 specimens were measured with calipers in height and length to the nearest 0.1 mm. A preliminary stable isotope analysis was performed on two *Hiattella* shells collected from the marine stratigraphic level at the Corrales Viejos site. These shells belong to different paired *Hiattella* specimens within the marine layer. For comparison, isotope analysis was also carried out on modern and Holocene *Hiattella* shells from other sites along the

Beagle Channel. Stable isotopes were measured at the Instituto de Geocronología y Geología Isotópica (INGEIS, CONICET-Universidad de Buenos Aires). The isotope ratios are presented in the standard (δ) notation and are given relative to V-PDB in ‰. The oxygen values of the water samples are relative to V-SMOW in ‰. These values were also compared with previous isotopic data on *Hiattella* shells (Gordillo, 1995) and *Mytilus* shells (Panarello, 1987; Obelie et al., 1998) from the Beagle Channel.

In foraminifers and ostracods, the total abundance (total A) and specific richness (S) were determined. For environmental determination, the index of Shannon-Wiener (H') (Buzas and Gibson, 1969) and the alpha index of Fisher (α) (Fisher et al., 1943) were applied for foraminifera association. The relative frequencies were made based on the assemblage of foraminifers. This analysis only considers the species whose relative abundance are equal to or greater than 1% in each level. As the ostracod fauna was very poor, it was not suitable for quantitative analyses.

6. Stratigraphic section

The studied profile is exposed along a 70 m road cut, 150 m southwest of the present coast line. The outcrop shows a total thickness of 4.70 m and it is found at a minimum elevation of 19 m above present sea level. The sedimentary beds occur in horizontal position and the base of the section is covered. Five main stratigraphic units have been recognized (Fig. 2):

- (1) a lower diamicton level, base covered. This level presents 40 cm of visible thickness and its matrix is lead grey, clayey sands, with dark brown mottled texture. The lowermost section of this layer is characterized by small clasts, with a mean diameter of less than 7 cm. In the upper section, clasts are larger, with a mean diameter of 7 cm and a maximum of 13 cm. The diamicton presents a lesser matrix content in this section. Clasts are (in general) angular and of varied lithology;
- (2) a 35 cm thick bed occurs over layer 1, mostly composed of dark brown laminated organic sediments, with macroscopic plant fragments and wood remnants. Over this organic level, a thin (4 cm thick) bed is found, composed of lead grey, structureless fine gravels and coarse sands. Medium texture, 17 cm thick gravels are found over this bed, with clasts of 1.5 cm mean diameter, in sandy-silty matrix. This layer does not present macroscopic sedimentary structures;
- (3) unconformably lying over layer 2 a muddy sediment with bioclastic fragments of marine invertebrates is found, with a thickness of 1.12 m, composed of a lower level, 57 cm thick, including remains of bivalve molluscs, gastropods and cirripeds (besides foraminifera and ostracods not visible to the naked eye), in a dark brown clayey matrix, and an upper level, 55 cm thick, with a percentage of organic remains close to 70%, also in clayey matrix, in which the shells occur with a lesser degree of fragmentation than in the lower level. The upper level presents a larger variety of species than the lower one. Some isolated, rounded clasts, with a mean diameter of 7 cm, are also observed in this bed. Shells from this layer have been radiocarbon dated as 41,000 BP, AMS method (Rabassa et al., 2008). The obtained date is very close to the accepted upper limit of the radiocarbon method, thus possibly corresponding to an infinite radiocarbon age, belonging perhaps to some moment of the last interglacial, that is, MIS 5, or even to an older interglacial period;
- (4) a thin shale level is found overlying these beds through a concordant contact, bearing interbedded sandy layers, fine gravels and laminae with high organic matter content. This level starts with structureless blueish shales, up to 20 cm thick.

This layer is overlain by a 7 cm thick bed, composed of fine gravel lenses with coarse sand matrix. Over this bed, a dark brown, 20 cm thick clayey layer is developed, showing some isolated volcanic rock clasts of up to 10 cm in mean diameter. Above these, the shales gradually reach high MnO₂ contents. This level of organic clays has a thickness of 30 cm and is interrupted by thin lenses composed of reddish brown fine sand, only 10–20 cm long and 1–2 cm thick. Above this, 50 cm thick, lead grey, massive clays lacking organic matter are found. In the uppermost 30 cm of this level, interbedded fine gravels and sands are observed;

- (5) in the highest portion of the studied section, a 1.40 m thick till bed is located. It is found unconformably overlying the aforementioned clays. It is composed of a light brown clayey matrix, with angular to subangular clasts of up to 20–30 cm in diameter. Laterally, this till bed is cut by up to 50 cm thick, medium-sand lenses. These sands are grayish, showing trough structures.

The present soil overlies the till and the sand lenses, with a thickness between 10 and 20 cm.

7. Faunal composition

7.1. Molluscs

Taxonomic composition is shown in Appendix 1. Most of the recovered taxa (94.5%) are molluscs: gastropods (55.5%), bivalves (33.5%) and chitons (5.5%). In addition, other taxa include cirripeds and spicules of echinoids. All identified species live today in the Beagle Channel. In the upper levels (samples 1, 2, 4; Table 1), mollusc fauna is diverse and dominated by trophonid (*Trophon*, *Fuegotrophon*, *Xymenopsis*) and buccinid gastropods (*Pareuthria*) and, myoid bivalves (*Hiatella*). However, in the lower levels (samples 3 and 5; Table 1), only a few taxa (*Mytilus*, Pectinidae, *Venus antiqua* and *Xymenopsis*) were collected. Fig. 3 shows some of the most significant and/or best preserved specimens. Most of the species are epifaunal organisms with different modes of life, including vagrant carnivorous, ectoparasites, passive browsers, and bysally attached or cemented suspension feeders, among others. Shells exhibit a highly variable state of preservation. Some groups (i.e. mytilids, pectinids) show a higher degree of breakage and fragmentation, so that their individual abundance cannot be estimated directly. However, most small taxa were recovered unbroken. With the exception of *Hiatella*, articulated bivalves were rare. Bioerosion and encrustation were scarce, and signs of abrasion inconspicuous.

The fauna considered here belongs to the traditional biogeographic Magellanic Province (Forbes, 1854), with some changes in the original limits. At present it is a U-shaped, wide, cold-temperate region, comprising both sides of southern South America between 56° S to about 40°–42° S. However, this Province has been discussed in a great number of publications (Stuardo, 1964; Hedgpeth, 1969; Viviani, 1979; Brattström and Johansen, 1983; among many others), and the different authors give different views on this region and its subdivisions. Furthermore, the progressive increase of the faunistic and environmental knowledge of southern South America (see Lancellotti and Vásquez, 1999), opened a controversial discussion in the scientific community mainly related with the criteria used to define the biogeographic units (Camus, 2001). In this regard, Stuardo and Valdovinos (1991) proposed the term “biogeographical province” as more appropriate. Even today, the biogeographic position of this region is an open question, but it must be better evaluated on the basis of a holistic approach which considers the historical development of the faunistic units.

7.2. Foraminifers

Taxonomic composition is listed in Appendix 2. A total of 28 genera of benthic foraminifera distributed among 51 species and 6 species with open nomenclature were determined (Fig. 4).

Individuals belong to the Suborders: Rotaliina (69%), Lagenina (31%), Miliolina (0.9%) and Spirillinina (0.01%). The C lower level is characterized mainly by *Elphidium macellum* (58%) and *Buccella peruviana* f. *typica* (26%). The other species were present in percentages lower than 5%. Total abundance was 19 individuals; S and H values were 5 and 1.1 respectively. According to the results in this level the fauna is poorly developed with broken and reworked individuals, and they represent the lowest values in abundance and diversity index (Fig. 5).

The C upper level is represented especially by *Cibicides disspars* (25%), *E. macellum* (13%), *B. peruviana* f. *campsi* (12%), *Elphidium alvarezianum* (8%) and *Cibicides variabilis* (7%). The rest of the species were present in percentages lower than 5%. Total abundance was represented by 2633 individuals; S and H values were 46 and 2.6 respectively and Fisher's α index was 8 (Fig. 5).

The S lower level is characterized mainly by *E. macellum* (39%), *E. alvarezianum* (30%) and *Discorbis peruvianus* (6%). The other species were recorded in percentages lower than 5%. Total abundance was represented by 274 individuals, S and H values were 19 and 1.8 respectively and Fisher's α index was 4.7 (Fig. 6).

The S upper level is represented especially by *C. disspars* (22%), *E. alvarezianum* (11%), *B. peruviana* f. *campsi* (10%) and *E. macellum* (9%). The rest of the species were present in percentages lower than 5%. Total abundance was represented by 878 individuals, S and H values were 36 and 2.7 respectively and Fisher's α index was 7.6 (Fig. 6).

Both lower levels, C and S, are characterized by *Elphidium* which is a typical genus of the inner shelf, found between 0 and 50 m in shallow waters (Boltovskoy, 1966; Murray, 1991, 2006) in the Argentine coast (Boltovskoy et al., 1980). This genus was particularly represented by the species *E. macellum* and *E. alvarezianum*. *E. macellum* is characteristic of the South Patagonian subprovince and is very abundant in the Malvin subprovince and also considerably larger than on the Patagonian coasts (Boltovskoy, 1976). It is found in the coastal zone and shallow waters of the inner shelf (Boltovskoy and Watanabe, 1980; Hromic, 2001). This species was found in southern South America: in Bahía Zenteno in the Strait of Magellan, fjords and Patagonian channels in shallow waters between 5 and 9 m, in Chile (Hromic and Águila, 1993; Hromic and Zúñiga-Rival, 2005; Zúñiga-Rival, 2006). *E. alvarezianum* is registered in the Malvinas current zone and in Southern Chile (Boltovskoy et al., 1980; Zapata and Moyano, 1997).

The foraminiferal faunas in the upper levels C and S have a higher abundance and a higher diversity than in the lower levels. These levels present a minor percentage of the species than were dominating in the lower levels for example *E. macellum* and *E. alvarezianum* and shows an increase of the percentage of other species such as *C. disspars* and *B. peruviana* f. *campsi*. *Elphidium lessonii*, *Globocassidulina subglobosa*, *Globocassidulina rossensis*, *Discorbis williamsoni*, *Cibicides aknerianus* and *Fissurina* spp., *C. disspars* occurs along the Argentine continental shelf between 35° S and 56° S. It is typical for the Malvin current zone (Boltovskoy et al., 1980). It has been cited as eubathyal species, and its abundance increases with depth; it is found in shallow waters to deep waters up to 4000 m, in Patagonian channels and fjords, and the Strait of Magellan (Boltovskoy and Watanabe, 1980; Hromic, 1996, 2002a, 2002b; Hromic and Zúñiga-Rival, 2005).

The presence of *E. macellum* and *C. disspars* together is commonly cited for Tierra del Fuego, Strait of Magellan, Patagonian fjords and

Table 1
Taxa composition, relative abundance and autoecology of the macrofauna examined.

TAXA	Bulk samples					Autoecology			
	1	2	3	4	5	Substrate	Life habit	Locomotion	Feeding type
BIVALVIA									
<i>Nucula falklandica</i> Preston		1l		1r		S	IN	Bur	DF
<i>Nucula</i> sp.	X					S	IN	Bur	DF
<i>Phylobrya</i> sp.		1l		1r		H	IN	Bys	SF
<i>Mytilus chilensis</i> Hupé	X		X		X	H	EP	Bys	SF
<i>Aulacomya atra</i> (Molina)	X					H	EP	Bys	SF
<i>Zygochlamys patagonica</i> (King and Brod.)	X			X	X	H	EP	Bys	SF
Pectinidae	X		X			H	EP	Bys	SF
<i>Rochefortia rochebrunei</i> Dall	1r	4r		1r + 3l		S	IN	Bur.	SF
<i>Neolepton concentricum</i> (Preston)	1r + 1l					S	IN	Bur.	SF
<i>Neolepton</i> sp 1	2	3r + 2l		6(r + l)		S	IN	Bur.	SF
<i>Neolepton</i> sp 2	1l			1(r + l)		S	IN	Bur.	SF
<i>Venus antiqua</i> (King and Brod.)	X		X	2r + 1l		S	IN	Bur	SF
Veneridae	X					S	IN	Bur	SF
<i>Hiatella</i> sp	6r + 2l	10(r + l)		7(r + l)		H,S	Var	Nes	SF
GASTROPODA									
<i>Puncturella conica</i> (Orbigny)		5		1		H	EP	V,P	BR
<i>Margarella violacea</i> (King and Brod.)	3					H,S	EP	V,A	BR
<i>Laevilitorina caliginosa</i> (Gould)	1					H	EP	V,A	BR
<i>Laevilitoridina</i> sp				1		H	EP	V,A	BR
<i>Crepidula dilatata</i> Lamarck	2	2				H	EP	V,P	SF
<i>Cerithiella</i> sp1		2							
Cerithidae	2								
<i>Trophon geversianus</i> (Pallas)	1			2		H,S	EP	V,A	CAR
<i>Trophon plicatus</i> (Lightfoot)		1				H,S	EP	V,A	CAR
<i>Trophon</i> sp		3				H,S	EP	V,A	CAR
<i>Fuegotrophon pallidus</i> (Broderip)		10		2		H,S	EP	V,A	CAR
<i>Xymenopsis muriciformis</i> (King and Brod.)	8	14	3	32		H,S	EP	V,A	CAR
<i>Xymenopsis buccineus</i> (Lamarck)	2					H,S	EP	V,A	CAR
<i>Glypteuthria meridionalis</i> (Smith)		11		2		H,S	EP	V,A	CAR
<i>Lachesis? euthroides</i> Melvill and Standen				1		H,S	EP	V,A	CAR
<i>Pareuthria ringei</i> (Strebel)		20		20		H,S	EP	V,A	CAR
<i>Pareuthria plumbea</i> (Philippi)	X			2		H,S	EP	V,A	CAR
<i>Odostomia</i> sp1	1			1		Ho	EP	V,A	ECT
<i>Osostomia</i> sp2	3			1		Ho	EP	V,A	ECT
<i>Turbonilla smithi</i> Strebel	1					Ho	EP	V,A	ECT
POLYPLACOPHORA									
<i>Callochiton</i> sp		1				H	EP	V,P	BR
<i>Tonica</i> sp.		1				H	EP	V,P	BR
CRUSTACEA									
Cirripedia Indet.	X	X	X	X		H	EP	Cem	SF
ECHINODERMATA									
Echinoidea Indet.	X	X		X		H,S	EP	V,P	OMN

Symbols: X: presence; (r + l): right + left, complete valve; l: left (single) valve; r: right (single) valve; S: soft; H: hard; Ho: Host; IN: infauna; EP: epifauna; Var: variable; Bur: burrower; Bys: bysally attached; Nes: nestle; V, A: vagrant, active locomotion; V,P: vagrant, passive locomotion; Cem: cementated; SF: suspension feeder; DF: deposit feeder; BR: browser; CAR: carnivorous; ECT: ectoparasite; OMN: omnivore. Samples: Upper level: 1, 2 and 4. Lower level: 3 and 5. Samples 2 and 3 correlates with subsample S. Samples 4 and 5 correlates with subsample C.

channels, Antarctica and Malvinas-Falkland Islands (Hromic, 1996, 2002a,b, 2009; Hromic and Zúñiga-Rival, 2005; Hromic et al., 2006). The proportion of these species is related to depth because *E. macellum* is especially found in shallow waters while *C. dispar* can live both in shallow waters as in deep zones (Boltovskoy, 1966).

B. peruviana is cited for the Strait of Magellan and Antarctica (Hromic, 1996, 1999). *B. peruviana* f. *campsi* has a wide distribution along of the Argentine continental shelf, between 32° S and 56° S; it has been found in inner shelf and estuary environments (Boltovskoy, 1976; Cusminsky et al., 2006; Bernasconi and Cusminsky, 2007; Cusminsky and Bernasconi, in press). This form is registered in the outer shelf and in the Malvin current zone (Boltovskoy and Watanabe, 1980; Boltovskoy et al., 1980; Kahn and Watanabe, 1980).

From a biogeographic viewpoint, the foraminiferal assemblage represents a typical fauna of the Malvin subprovince (Boltovskoy, 1976; Boltovskoy et al., 1980; Kahn and Watanabe, 1980). It is found in southern Chile, the Austral zone, in the Strait of Magellan and Tierra del Fuego (Hromic, 1999; Zúñiga-Rival, 2006).

7.3. 7.3. Ostracods

The taxonomic list of ostracods is given in Appendix 3. These taxa belong to the Order Podocopida.

The ostracods are absent in the C lower level, while in the S lower level, the fauna is characterized by few specimens of *Oculocytheropteron burdwoodbankensis* and broken individuals of *Xestoleberis* sp. and *Austroaurilla thelli*.

The ostracod assemblage is poorly represented by *Austroaurilla recurvirostrata*, *Argilloecia meridionalis* and *Ambostracon bertelsae* in the C upper level and *O. burdwoodbankensis* and *Procythereis torquata* in the S upper level.

A. meridionalis, *A. recurvirostrata*, *O. burdwoodbankensis* and *Procythereis torquata* are registered in the Southern Ocean, Islas Malvinas; Tierra del Fuego; Isla de los Estados; Magellan straits; Canal Concepción and Burdwood Bank (Skogsberg, 1928; Maddocks, 1968; Hartmann, 1993; Whatley et al., 1995, 1996b, 1997a, 1997b, 1998; Whatley and Cusminsky, 2002). The biogeographical distribution of these species corresponds to the Fuegian/

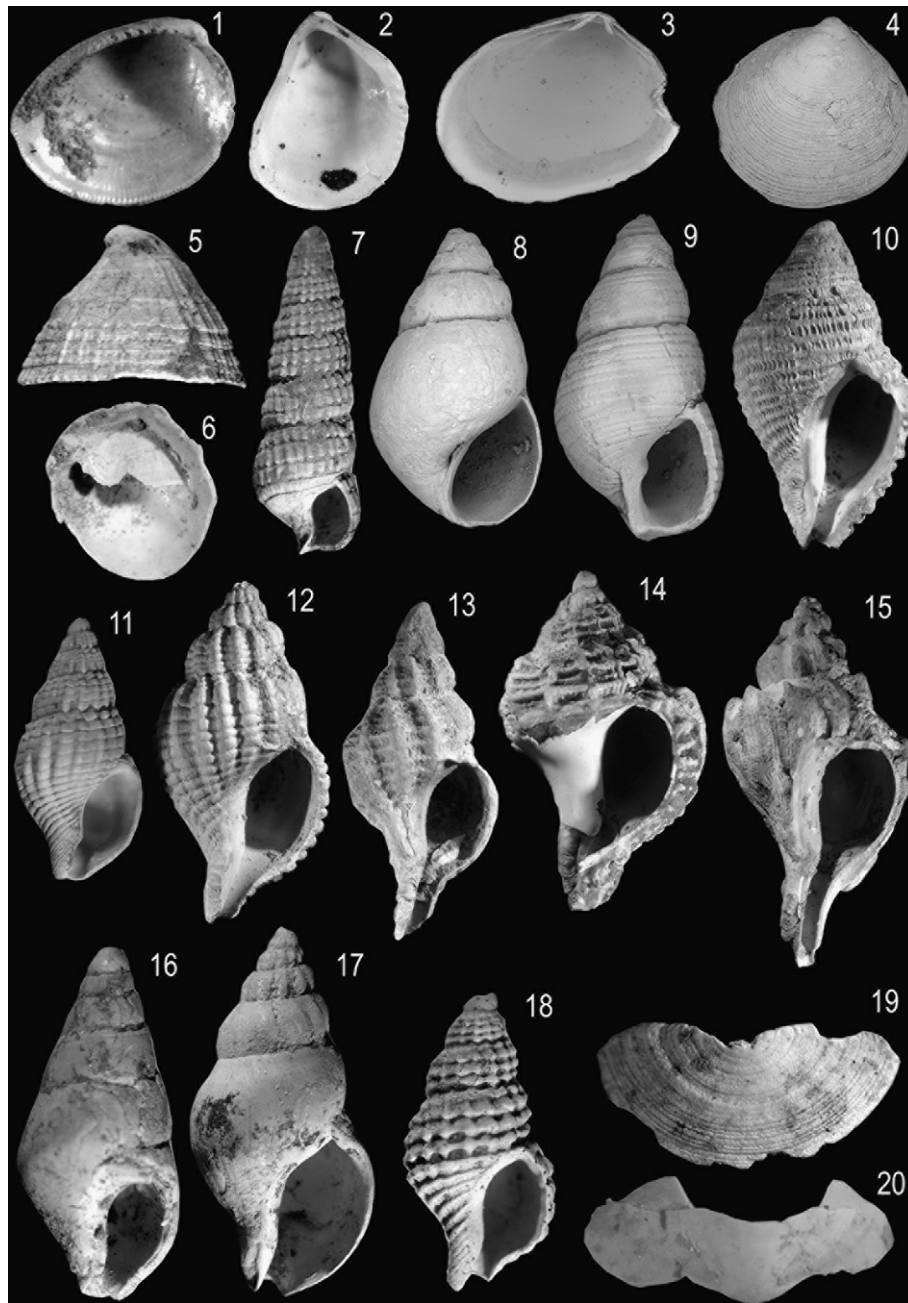


Fig. 3. Most characteristic or best preserved species recovered from the studied stratigraphic section at Corrales Viejos site. Bivalves: 1, *Nucula falklandica* Preston ($L = 3.3$ mm), CEGH-UNC23898; 2, *Philobrya* sp. ($L = 5.0$ mm), CEGH-UNC23899. 3, *Rochefortia rochebrunei* Dall ($L = 2.8$), CEGH-UNC23887; 4, *Neolepton concentricum* (Preston) ($L = 1.5$ mm), CEGH-UNC22764. Gastropods: 5, *Puncturella conica* (Orbigny) ($L = 7.2$ mm), CEGH-UNC23909; 6, *Crepidula dilatata* Lamarck ($L = 3.7$ mm), CEGH-UNC23901; 7, *Cerithiella* sp. ($L = 15.0$ mm), CEGH-UNC23908; 8, *Odostomia* sp1. ($L = 3.3$ mm), CEGH-UNC23897; 9, *Odostomia* sp2. ($L = 2.4$ mm), CEGH-UNC23896; 10, *Trophon* sp. ($L = 17.5$), CEGH-UNC23917; 11, *Glypteuthria meridionalis* (Smith) ($L = 9.0$ mm), CEGH-UNC23918; 12, *Xymenopsis muriciformis* (King and Broderip) ($L = 18.7$ mm), CEGH-UNC23928; 13, *Fuegotrophon pallidus* (Broderip) ($L = 19.0$ mm), CEGH-UNC23913; 14, *Trophon geversianus* (Pallas) ($L = 26.0$ mm), CEGH-UNC23916; 15, *Trophon plicatus* (Lightfoot) ($L = 28.7$ mm), CEGH-UNC23914; 16, *Pareuthria plumbea* (Philippi) ($L = 8.5$ mm), CEGH-UNC23905; 17, *Pareuthria ringei* (Strebel), ($L = 25.5$ mm), CEGH-UNC23906; 18, *Lachesis euthroides* Melvill and Standen, ($L = 8.0$ mm), CEGH-UNC23912. Chitons: 19, *Callochiton* sp. ($L = 6.2$ mm), CEGH-UNC23902; 20, *Tonicia* sp. ($L = 5.3$ mm), CEGH-UNC23903.

Magellanic subprovince and the Southern Patagonian/Falkland subprovince (Whatley et al., 1996a; Cusminsky and Whatley, 2008). *Austrourila theeli* is found in the subprovinces mentioned above and in the littoral between Península Valdez and Mar del Plata, Río de La Plata estuary (Whatley et al., 1987, 1997b, 1998) and *A. bertelsae* is located in shelf sediments off the coast of the southern Brazil and northern Patagonia (Whatley et al., 1997b). According to Whatley et al. (1996a) and Cusminsky and Whatley (2008), the former species is cited in the Bonaerensian province as

well, and the latter is present between the Bonaerensian province and the Southern Brazilian subprovince (Whatley et al., 1996a).

8. Size and shape of *Hiatella*

The bivalve *Hiatella* is a wide tolerant ecological taxon, able to bore, to nestle, or to live attached by byssus to other epifauna or substrates. In this regard, fossil and living *Hiatella* shells are morphologically highly variable. Thus, further paleontological

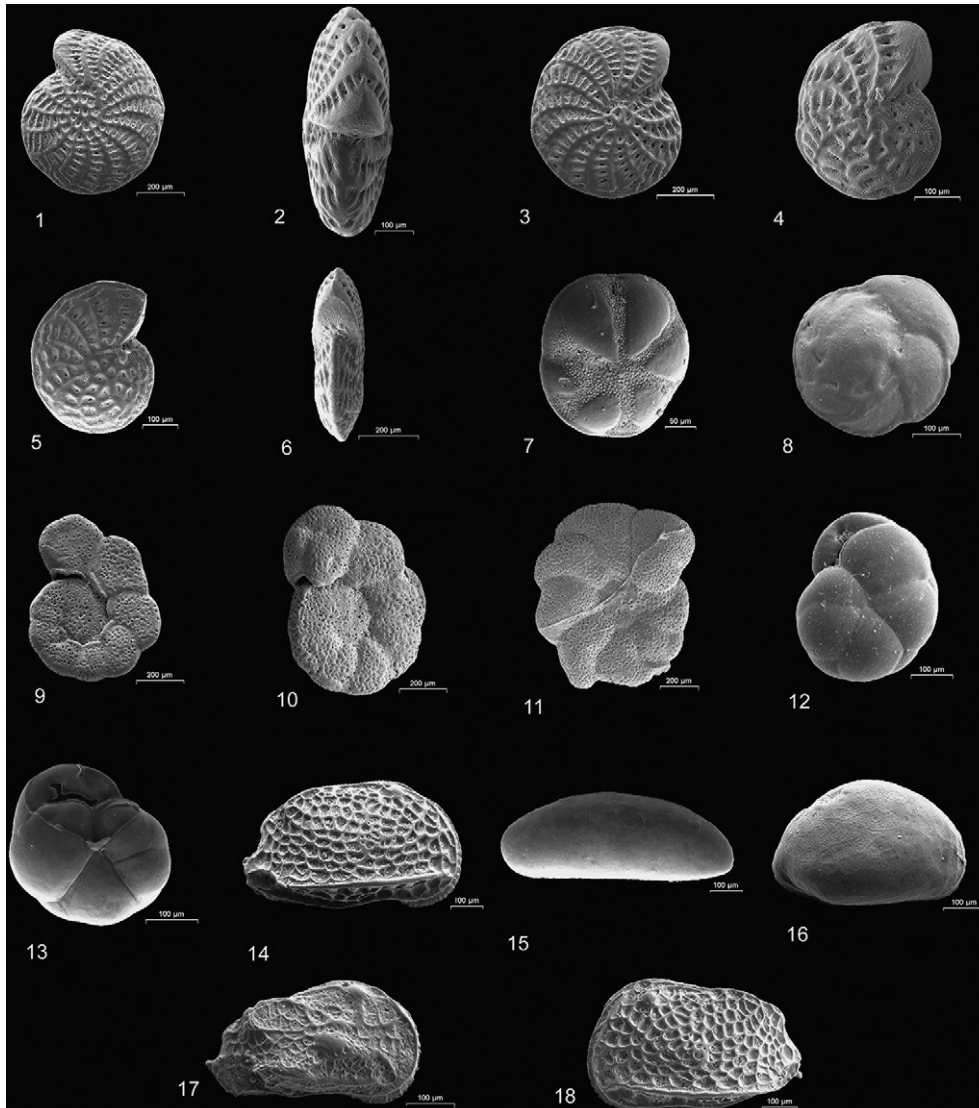


Fig. 4. Foraminifers and ostracods species: 1, *Elphidium macellum* (Fitchel and Moll), MLP-Mi.1766, C upper level. 2, *Elphidium macellum* (Fitchel and Moll), MLP-Mi. 1767. 3, *Elphidium macellum* (Fitchel and Moll), MLP-Mi. 1768, C upper level. 4, *Elphidium alvarezianum* (d'Orbigny), MLP-Mi. 1769, C upper level. 5, *Elphidium alvarezianum* (d'Orbigny), MLP-Mi. 1770. 6, *Elphidium alvarezianum* (d'Orbigny), MLP-Mi. 1771, S upper level. 7, *Buccella peruviana* f. *campsi* (Boltovskoy), MLP-Mi. 1772, C upper level. 8, *Buccella peruviana* f. *campsi* (Boltovskoy), MLP-Mi. 1773, C upper level. 9, *Cibicides dispars* (d'Orbigny), MLP-Mi. 1774, C upper level. 10, *Cibicides dispars* (d'Orbigny), MLP-Mi. 1775, C upper level. 11, *Cibicides variabilis* (d'Orbigny), MLP-Mi. 1776, S upper level. 12, *Globocassidulina rossensis* (Kennett), MLP-Mi. 1777. 13, *Globocassidulina rossensis* (Kennett), MLP-Mi. 1778, S upper level. 14, *Austroaurila recurvirostrata* (Skogsberg), MLP-Mi. 1779, C upper level. 15, *Argilloecia meridionalis* Brady, MLP-Mi. 1780, C upper level. 16, *Oculocytheropteron burdwood-bankensis* Whatley and Cusminsky, MLP-Mi. 1781, S upper level. 17, *Ambostracon bertelsae* (Sanguinetti, et al.) MLP-Mi. 1782, *Procythereis torquata* Skogsberg, MLP-Mi. 1783. Scale = 200 μm (Figs. 1, 3, 6, 9, 10); 100 μm (Figs. 2, 4, 5, 8); 50 μm (Fig. 7).

research considering size and shape of *Hiatella* shells would contribute to evaluate the palaeoenvironmental meaning of its great plasticity. It was suggested (Strauch, 1968, 1971) that shell length of *Hiatella* is inversely related to winter temperatures and consequently, it is useful in the estimation of Cenozoic paleotemperatures. However, other authors (Rowland and Hopkins, 1971) believe that the mode of life of each population is what regulates the size of the individuals. In addition, the great variation in the shell morphology of *Hiatella* obscures species identification in adult specimens. A revision of the genus *Hiatella* is still in progress, and the origin and radiation of *Hiatella* remain controversial (Vermeij, 1991; Gordillo, 2001). Recent works show that living *Hiatella* from geographically distant sites exhibit several morphological anatomical differences (see Simone and Penschazadeh, 2008) and at least two larval morphs were reported from the Chilean coast (Díaz, 2005, in Campos and Díaz, 2007).

Here, fossil and living *Hiatella* shells from different sites along the Beagle Channel are compared in size and shape (Figs. 7–9).

Shells of *Hiatella* recovered from the studied section are short and deformed (Figs. 7–9). The fact that most of them were found within empty tests of barnacles would explain their shape. Also, living *Hiatella* specimens collected within cirripeds (Fig. 7) resemble the Pleistocene shells. On the other hand, modern *Hiatella* specimens living as infauna or semi-infauna (Figs. 7–9) as well as Holocene *Hiatella* specimens belonging to benthic infaunal paleocommunities (Figs. 7–9) are larger, with more regular shape than epifaunal specimens. Thus, a connection between their size and shape with an epifaunal or a semi-infaunal/infaunal mode of life is indicated here. Bysally attached forms exhibit an intermediate size between the nestler forms and the partially buried taxa (Fig. 7). In summary, fossil and living *Hiatella* from the Beagle Channel have a wide ecological plasticity, adapting to different

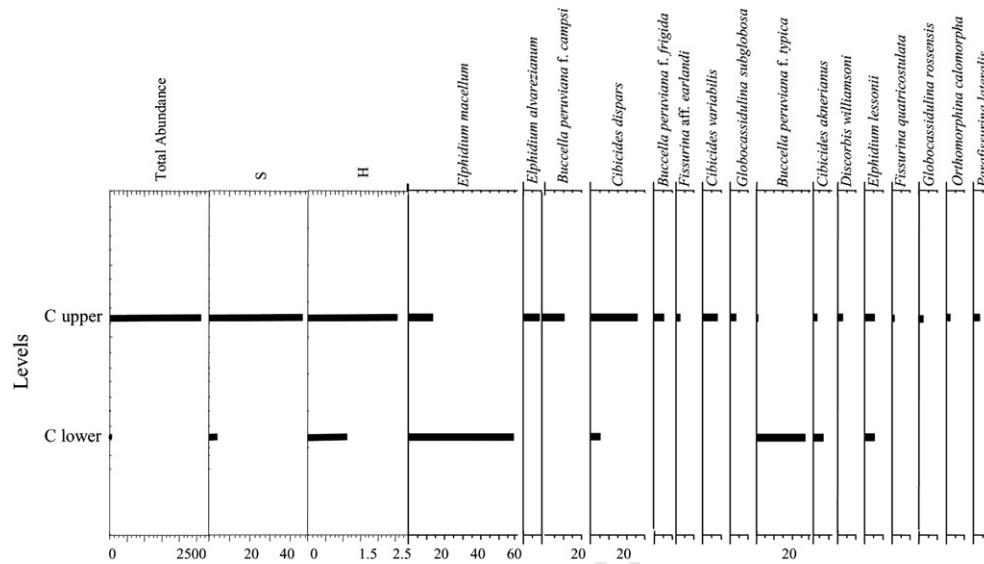


Fig. 5. Total abundance (Total A), Species richness (S) and Shannon-Weaver diversity index (H) and foraminifer's species in lower and upper C levels, with 1% or more of abundance relative.

substrates and mode of life, and adopting a wide morphologic variation in size and shape.

9. Stable isotopes of *Hiatella* shells from the Beagle Channel

Preliminary data (Table 2, Fig. 10) show carbon and oxygen isotopes values reasonable for the region, agreeing with previous values by Panarello (1987) and Obelic et al. (1998). Heterogeneous values on modern shells are probably related to varying influence of freshwater since that these mollusc species are able to live in the vicinity of rivers or streams flowing into the Beagle Channel.

In the Beagle Channel, isotope ratios of the Pleistocene *Hiatella* shells were similar to isotopic values obtained for Holocene *Hiatella* shells. The main problem faced during the calculation of paleotemperatures was the lack of information on the salinity and isotopic composition in the Beagle Channel surface sea water, also noted by Obelic et al. (1998).

Notwithstanding, Pleistocene shells are slightly heavier in oxygen and slightly lighter in carbon than the modern ones, which could indicate that Pleistocene shells were deposited in a high energy environment (such as an exposed embayment) within a truly marine environment (away from freshwater influence), and during a cooler period (with a difference $<1^\circ\text{C}$) relative to the present mean annual temperature. However, more measurements on a statistically significant number of samples are necessary to evaluate if isotopic compositions of *Hiatella* reflect original seawater conditions. In this regard, sclerochronological analysis of *Hiatella* shells should also be considered in the future to have more precise information on the life history and environmental records preserved in fossil and modern shells. Previous works on Late Quaternary deposits from Ontario (Canada) showed that geochemistry of *Hiatella* shells serves as proxies of original seawater chemistry (Brand and McCarthy, 2005).

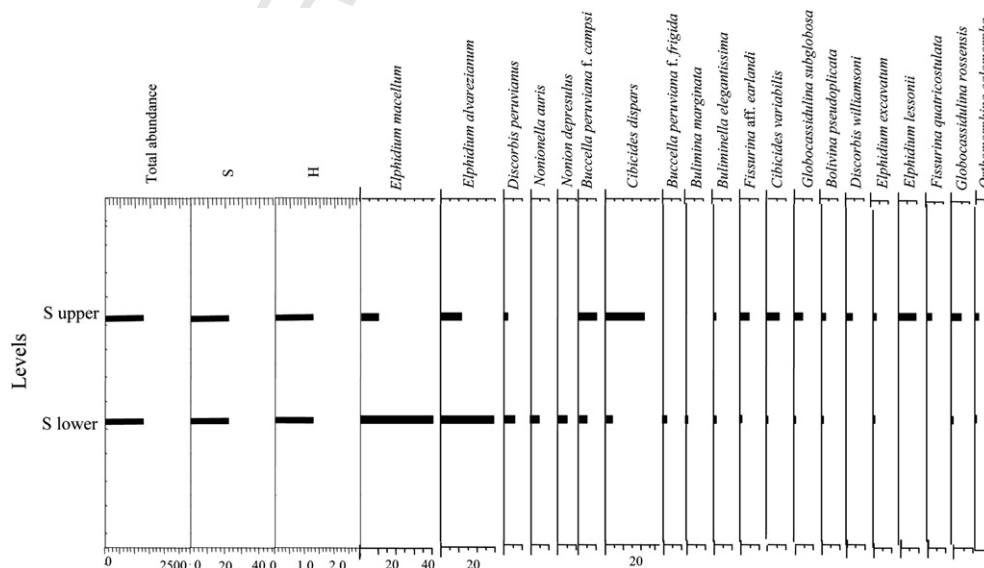


Fig. 6. Total abundance (Total A), Species richness (S) and Shannon-Weaver diversity index (H) and foraminifer's species in lower and upper S levels, with 1% or more of abundance relative.

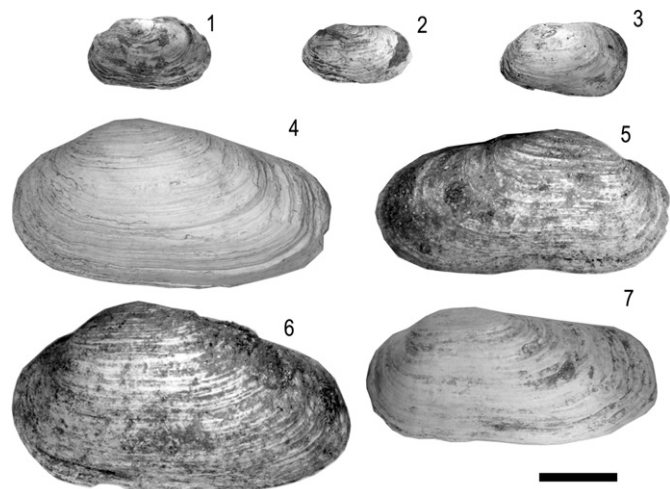


Fig. 7. *Hiatella* specimens from different localities along the Beagle Channel showing variations in size. 1–2. Pleistocene *Hiatella* shells. 3–4. Modern *Hiatella* shells. 5–7. Holocene *Hiatella* shells. Figs. 1–3 correspond to *Hiatella* living within barnacle tests (epifaunal mode of life), and 4–7 to *Hiatella* living partially buried (infaunal mode of life). Scale = 10 mm.

10. Some comments related to the altitude of the interglacial marine beds of Navarino Island

The Beagle Channel coastline neotectonic uplift is clearly related to the motion between the South American, Antarctic and Scotia plates (Menichetti et al., 2008). Holocene fault scarps and landslides, among others, show significant tectonic activity along this alignment (Dalziel, 1989). The tectonic valley that today occupies the Beagle Channel was covered by ice during the last glaciations (Bujalesky, 2007) with a maximum ice thickness of approximately 1400–1500 m during the LGM (Rabassa et al., 1990; Planas et al., 2002).

Along the northern coast of the Beagle Channel, several Holocene raised beaches were previously recognized, tectonic uplift the apparent cause of their elevation. They reach maximum

elevations of 10 m above the present sea level, with an average tectonic uplift of 1.5–2.0 mm/year for the last 6 ka (Rabassa et al., 1986; Rabassa, 1987), and a rate of 2.9 mm/year for the last 1 ka (Gordillo et al., 1992).

In agreement, raised paleobeaches have also developed along the southern coast of the Beagle Channel. On Navarino Island, at Punta Guerrico, located about 15 km west of the Corrales Viejos studied section, a raised gravel beach berm interfingers with an archaeological shell midden. Fine leveling determined that the top of the beach ridge is 10.6 m above the present sea level (Pino et al., 2001). The uncalibrated ^{14}C age of a shell sample of the midden is 6495 ± 60 BP (AA 10918), resulting in an approximate uplift rate of 1.6 mm/yr that agrees with the data published for the northern coast of the channel. Due to the proximity of both sections, it would be expected that Punta Guerrico and Corrales Viejos be under the same rate of tectonic uplift. However, the altitude of Corrales Viejos terrace is 19 m a.s.l., which would provide an estimate of one order of magnitude lower than the mean tectonic uplift if this had been the same during the last 110 ka.

The tectonic conditions for the easternmost portion of the Beagle Channel at least during the Holocene have been different from those for the central or western parts during such period. This has been clearly shown by Rabassa et al. (2004), who found that east of the Harberton Ranch (in the northern coast of the Beagle Channel, in front of Puerto Williams), the mid-Holocene marine deposits are actually below present sea level. Therefore, the Corrales Viejos marine sediments would have been down-warped instead during the Late Holocene, thus explaining their relatively limited elevation above present sea level, when compared to the Holocene raised beaches located to the west. In other areas, for instance, where uplifting tectonic movements have been constant throughout the Quaternary, the interglacial terraces near Valdivia (Chile), at 39°S, reach 60 m a.s.l. (Latorre et al., 2007). A mean uplift value of only about 0.2 mm/year calculated for the Corrales Viejos section indicates how important the Late Holocene neotectonic subsidence has been, affecting the relative altitude of the interglacial deposit and compensating their previous up-raising, having been affected before by Late Pleistocene neotectonic uplift and/or isostatic rebound during and since last Interglacial (MIS 5e).

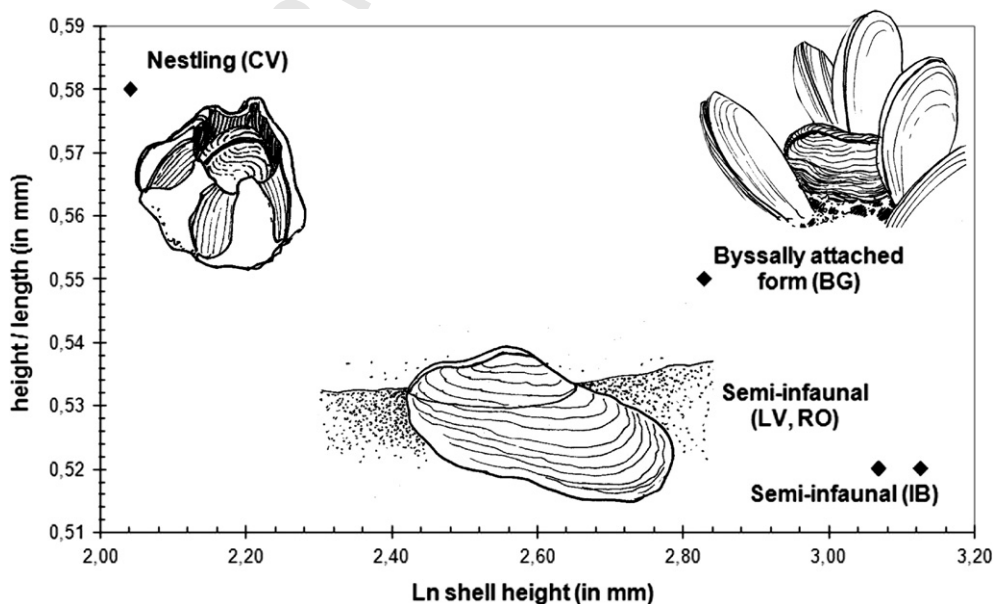


Fig. 8. Diagram showing size variations among *Hiatella* shells with different modes of life. See abbreviations in the map. (BG: Bahía Golondrina, CV: Corrales Viejos, IB: Islas Bridges, LV: Laguna Verde, RO: Río Ovando.)

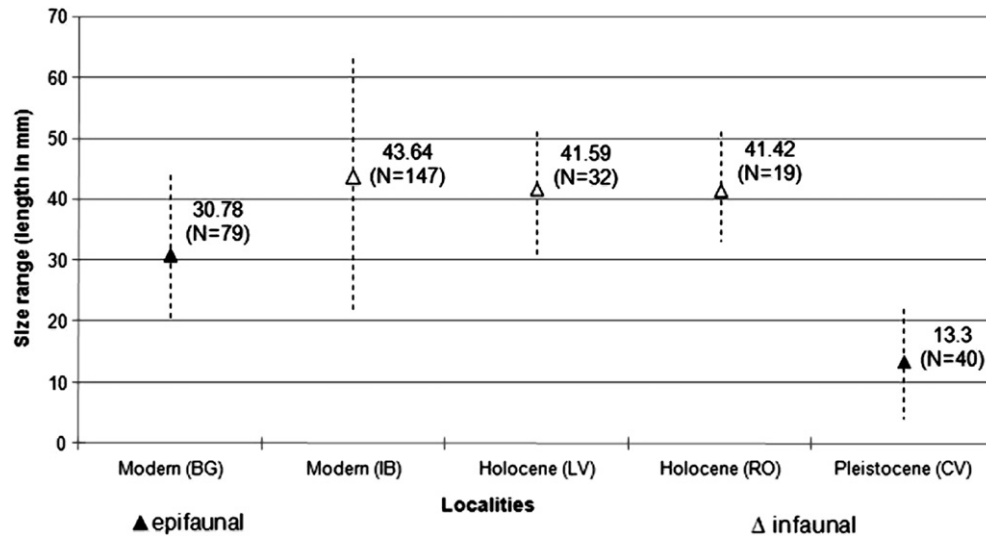


Fig. 9. Size of modern and fossil *Hiatella* shells from the Beagle Channel.

11. Paleoenvironmental interpretation of the bed unit and the fossil assemblage

The analysis of the stratigraphic section indicates that, at the base, sedimentation took place in a continental, glacial environment, with till accumulation. This episode was followed by the development of a peatland environment, under a wetter and less cold climate. The overlying marine sediments were formed during a transgressive event (possibly during MIS 5e), with the instatement of a shallow coastal environment, firstly represented by sands and gravels, and later by fragmented shell levels and clays, indicating a gradual deepening of the marine environment. The presence of organic matter bearing clayey and sandy levels over the marine deposits shows the development of a transitional regressive environment, with marshy characteristics. The till deposits of the uppermost section indicate the occurrence of another cold episode that generated a new glacial advance (probably during MIS 2 and/or 4?). These deposits were eroded in their highest portion by glaciofluvial channels, which were partially in-filled by sands, perhaps in an ice-contact environment.

Taxonomic composition and ecological characterization of the macrofauna in the marine bed suggest the existence of a shallow coastal environment. Besides, the presence of disarticulated valves, and the degree of fragmentation of the macrofauna suggest marine paleoenvironments characterized by strong bottom currents. Further support is given by the high occurrence of remains of

barnacles and sea urchins, both typically associated to wave exposed areas in the shallow hard bottoms.

The co-occurrence of taxa associated to different substrates shows that this shell bed can be regarded as a mixture of molluscs originally inhabiting several local habitats and different local paleocommunities, which suffered post-mortem displacement before final burial. As shells included in the marine bed may be derived from reworking of life assemblages, from older assemblages exhumed during shoreface retreat, or are shells transported from immediately adjacent coeval environments (see Craig and Hallam, 1963; Fürsich, 1990; Cantalamessa et al., 2005); perhaps, they correlate with the “multi-habitat time-averaged assemblage” of Kidwell and Bosence (1991).

Comparing the molluscan faunas recovered from the lower and from the upper marine layers, a higher number of taxa in the upper layer are clearly demonstrated. This increase is interpreted on the basis of ecosystem transition which started with vacant niches first occupied by opportunistic species, and/or more tolerant taxa to low salinities, and subsequent replacement by more diverse taxa. This diversification would be associated to the proliferation of habitats occurred under truly marine conditions during interglacial times.

Similarly, considering the microfauna, an increment in the number of taxa and in their abundance for the upper layer is also observed, that would be reflecting an environmental change from coastal marine conditions to normal marine conditions, with a rising of sea level.

Table 2

Oxygen and carbon isotope obtained on fossil and modern *Hiatella* and *Mytilus* shells from the Beagle Channel.

Sample	Species	Age	$\delta^{13}\text{C} \text{ ‰}$	$\delta^{18}\text{O} \text{ ‰}$	Source
BG2	<i>Hiatella</i>	Modern/recent shell	0.4 ± 0.10	0.4 ± 0.10	This work
LR3	<i>Hiatella</i>	Holocene shell (ca. 7500)	1.6 ± 0.10	0.8 ± 0.10	This work
ER	<i>Hiatella</i>	Holocene shell (ca. 4000 yr BP)	1.5 ± 0.10	1.5 ± 0.10	This work
CV1	<i>Hiatella</i>	Pleistocene shell	1.1 ± 0.10	1.3 ± 0.10	This work
CV2	<i>Hiatella</i>	Pleistocene shell	1.1 ± 0.10	1.3 ± 0.10	This work
BG1	<i>Hiatella</i>	Modern/recent shell	1.97 ± 0.24	1.05 ± 0.10	Gordillo (1995)
AK	<i>Hiatella</i>	Holocene shell (ca. 4400 yr BP)	1.48 ± 0.18	1.29 ± 0.06	Gordillo (1995)
LR2	<i>Hiatella</i>	Holocene shell (ca. 5900 yr BP)	1.36 ± 0.10	0.23 ± 0.10	Gordillo (1995)
CB1	<i>Mytilus</i>	Modern shell / sea water	0.8 ± 0.1	0.3 ± 0.1	Panarello (1987)
CB2	Several species	Modern shells / sea water	1.6 ± 0.1^a	0.87 ± 0.1^a	Panarello (1987)
CB3	<i>Mytilus</i>	Modern shells/ pure sea water	-0.08 ± 0.31	0.17 ± 0.27	Obelic et al. (1998)
CB4	<i>Mytilus</i>	Modern shells/ influenced by freshwater	-0.35 ± 0.45	-0.16 ± 0.38	Obelic et al. (1998)

^a Average values

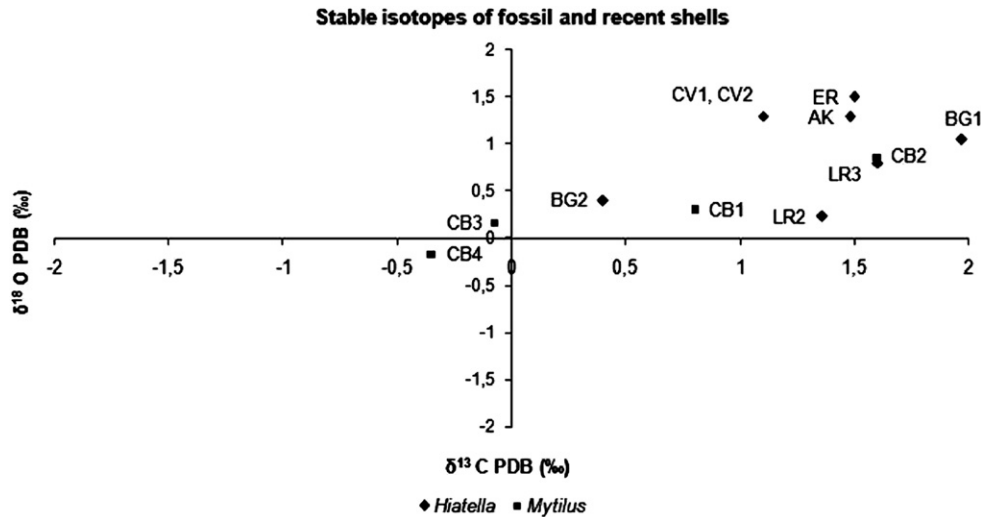


Fig. 10. Relationship between oxygen and carbon isotopic composition of *Hiattella* and *Mytilus* shells from the Beagle Channel. See abbreviations in Table 2.

Previous works on Holocene foraminifers (Laprida and Bertels-Psotka, 2003; Cusminsky et al., 2006; Bernasconi and Cusminsky, 2007) and molluscs (Gordillo et al., 2005) also show variations associated to paleoenvironmental changes. Laprida and Bertels-Psotka (2003) and Bernasconi and Cusminsky (2007) described changes in the percentages of *Elphidium* spp. and *B. peruviana* f. *campsi* along the core, recognizing a transition from restricted conditions towards normal marine conditions. Also, Cusminsky et al. (2006) showed variations in recent sediments at the Bahía Blanca estuary, related with a predominance of *Elphidium* spp. in shallow waters and *B. peruviana* f. *campsi* and *Cibicides* spp. best represented in deeper waters.

In the Beagle Channel, Gordillo et al. (2005) also evaluated changes in mollusc faunal composition during the Holocene. They recognized a first step of faunal changes associated to oceanographic episodes after deglaciation (early Holocene), and then a second step (middle Holocene) related with a short period of warmer conditions (the Hypsithermal).

The faunistic assemblage considered in this work provides a very good picture of the overall coastal benthic biodiversity patterns in the region. At a regional scale, the composition of mollusc species shows remarkable similarity with the present-day fauna. Previous works in Chile (Ortlieb et al., 1994; Guzmán et al., 2000; Nielsen and Valdovinos, 2008; Rivadeneira and Carmona, 2008) and in Antarctica (Igarashi et al., 1995) also found large similarities between Pleistocene and modern assemblages. However, at a local scale, several authors (Gordillo and Isla, 2008; Nielsen and Valdovinos, 2008; Rivadeneira and Carmona, 2008) described differences when comparing Pleistocene benthic communities with their adjacent modern counterparts. For example, Nielsen and Valdovinos (2008) observed that the Pleistocene fauna of Tubul Formation, in central Chile, resembles most the present-day fauna of southern Chile. In northern Tierra del Fuego, on the Atlantic coast, Gordillo and Isla (2008) also observed the replacement of a Pleistocene infaunal paleo-community for a modern epifaunal benthic community. In this regard, the Pleistocene *Hiattella*-cirriped assemblage described in our study apparently has no modern equivalent in the region. Based on the observations from the Beagle Channel shallow benthic communities, it appears that *Hiattella* only sporadically appears associated with empty barnacles. Thus, considering these local changes, the existence of local variations affecting the structure of local communities cannot be ruled out.

Finally, contrasting the two hypotheses concerning to the meaning of size and shape of fossil and living *Hiattella* from the Beagle Channel, it appears that these polymorphic shells primarily reflect the living habits of the animal. For example, Pleistocene *Hiattella* shells living inside dead barnacles are short and deformed, while extant and Holocene *Hiattella* specimens living partly buried in sandy substrates are larger and more oval-oblong. Intermediate sizes adopt modern byssally-attached forms of *Hiattella*, living alone among *Mytilus* clusters or *Macrocystis* holdfasts.

In a previous work (Gordillo, 1995), a slight correlation between *Hiattella* size and temperatures was found: i.e., *Hiattella* specimens from Brazil and lower latitudes along the Atlantic Argentine coast are smaller than those from higher latitudes (i.e., Tierra del Fuego). Thus, although it appears that size and shape of *Hiattella* shells from the Beagle Channel are best controlled by its mode of life, on a broader scale a control by temperature cannot be ruled out.

12. Final remarks

In relation to biodiversity, the marine unit of Navarino Island represents the richest and most diverse macro-and-micro Pleistocene assemblage recovered from southern South America and the closest one to the Antarctic Circumpolar Current in the entire Southern Hemisphere. This unique record also indicates that at the time of the marine layer deposition, the environmental conditions in this region were similar to those today.

It is known that climatic deterioration during Pliocene-Pleistocene glaciations produced environmental changes that normally resulted in regional or local extinctions followed by a repopulation by migrants from other areas. Taking into account that during the Pleistocene the entire Beagle Channel basin was repeatedly glaciated, it is very likely that after a glacial period, the vacant (just deglaciated) areas were occupied by new communities formed by immigration of taxa living in any location with geographic access to the new marine environment. This colonization of species and the successful establishment of communities would be favored by the habitat heterogeneity within the Beagle Channel. In this regard, the Pleistocene appears to be a key period for the understanding of the origin of the modern marine fauna of this region. The present work based on molluscs, ostracods and foraminifers represents an initial approach to the further study of biogeographical and evolutionary links between the southernmost tip of South America and the Antarctic continent during the Quaternary.

Uncited references

Brady, 1880; Müller, 1908.

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Appendix 1. : List of MOLLUSCA

Phylum MOLLUSCA Linnaeus, 1758
 Class BIVALVIA Linnaeus, 1758
 Family NUCULIDAE Gray, 1824
Nucula falklandica Preston, 1912
Nucula sp.
 Family PHILOBRYIDAE Bernard, 1897
Philobrya sp.
 Family MYTILIDAE Rafinesque, 1815
Aulacomya atra (Molina, 1782)
Mytilus chilensis Hupé in Gay, 1854
 Family PECTINIDAE Rafinesque, 1815
Zygochlamys patagonica (King and Broderip, 1832)
 Family LASAEIDAE Gray, 1842
Rochefortia rochebrunei Dall, 1908
 Family NEOLEPTONIDAE Thiele, 1934
Neolepton concentricum (Preston, 1912)
Neolepton sp 1
Neolepton sp2
 Family VENERIDAE Rafinesque, 1815
 Veneridae Indet.
Venus antiqua (King and Broderip, 1832)
 Family HIATELLIDAE Gray, 1824
Hiatella sp.
 Class GASTROPODA Cuvier, 1797
 Family FISSURELLIDAE Fleming, 1822
Puncturella conica (Orbigny, 1841)
 Family TROCHIDAE Rafinesque, 1815
Margarella violacea (King and Broderip, 1832)
 Family EATONIELLIDAE Ponder, 1965
Eatoniella sp.
 Family LITTORINIDAE Children, 1834
Laevilitorina caliginosa (Gould, 1848)
Laevilitorina sp.

Family CALYPTRAIDAE Lamarck, 1809
Crepidula dilatata Lamarck, 1822
 Family CERITHIOPSIDAE (s.l.) Adams H. and A. Adams, 1853
Cerithiella sp.
 Family MURICIDAE Rafinesque, 1815
Trophon geversianus (Pallas, 1769)
Trophon plicatus (Lightfoot)
Trophon sp.
Fuegotrophon pallidus (Broderip, 1832)
Xymenopsis muriciformis (King and Broderip, 1832)
Xymenopsis buccineus (Lamarck, 1816)
 Family BUCCINULIDAE Finlay, 1928
Glypteuthria meridionalis (Smith, 1881)
Lachesis euthroides Melvill and Standen, 1898
Pareuthria plumbea (Philippi, 1844)
Pareuthria ringei (Strebel, 1905)
 Family PYRAMIDELLIDAE Gray, 1840
Odostomia sp. 1
Odostomia sp. 1
Turbonilla smithi Strebel (Pfeffer, MS), 1905
 Class POLYPLACOPHORA Gray, 1821
 Family CALLOCHITONIDAE Plate, 1901
Callochiton sp.
 Family CHITONIDAE Rafinesque, 1815
Tonica sp.

Appendix 2. : List of FORAMINIFERA

Order FORAMINIFERIDA Eichwald, 1830
 Suborder MILIOLINA Delage and Hérouard, 1896
 Family HAUERININAE Schwager, 1876
Quinqueloculina patagonica d' Orbigny, 1839
Quinqueloculina sp.
 Suborder LAGENINA Delage and Hérouard, 1896
 Family VAGINULINIDAE Reuss, 1860
Amphicoryna scalaris (Batsch, 1791)
 Family STILOSTOMELLIDAE Finlay, 1947
Orthomorphina calomorpha (Reuss, 1866)
Lenticulina limbosa Reuss, 1863.
Lenticulina rotulata Lamarck, 1804
Neolenticulina peregrina (Schwager, 1866)
 Family LAGENIDAE Reuss, 1812
Lagenca caudata (d' Orbigny, 1839)
Lagenca interrupta Williamson, 1848
Lagenca montagui Silvestri, 1902
Lagenca striata (d' Orbigny, 1839)
 Family ELLIPSOLAGENIDAE Silvestri, 1923
Oolina caudigera (Wiesner, 1931)
Oolina globosa (Montagu, 1784)
Oolina lineata (Williamson, 1848)
Oolina melo d' Orbigny, 1839
Oolina sp.
Fissurina earlandi Parr, 1950.
Fissurina laevigata Reuss, 1850.
Fissurina quadricostulata (Reuss, 1870)
 Suborder ROTALIINA Delage and Hérouard, 1896
 Family BOLIVINIDAE Glassner, 1937
Bolivina ordinaria Phleger and Parker, 1950
Bolivina striatula Cushman, 1922
Bolivina translucens Phleger y Parker, 1951.
Brizalina pseudoplicata (Heron-Allen and Earland, 1930)
 Family CASSIDULINIDAE d'Orbigny, 1839
Cassidulina laevigata d'Orbigny, 1826.
Globocassidulina crassa (d' Orbigny, 1839)

- 1671 *Globocassidulina minuta* (Cushman, 1933)
 1672 *Globocassidulina subglobosa* (Brady, 1881)
 1673 *Globocassidulina rossensis* (Kennett, 1967)
 1674 *Cassidulinoides parkerianus* (Brady, 1881)
 1675 Family BULIMINIDAE Jones, 1875
 1676 *Bulimina marginata* d'Orbigny, 1826.
 1677 Family BULIMINELLIDAE Hofker, 1951
 1678 *Buliminella elegantissima* (d'Orbigny, 1839)
 1679 *Angulogerina angulosa* f. *angulosa* (Williamson, 1858)
 1680 *Angulogerina angulosa* f. *occidentalis* (Cushman, 1923)
 1681 Family FURSENKOINIDAE Loeblich and Tapan, 1961
 1682 *Furksenkoina schreibersiana* (Czjzek, 1848)
 1683 Family DISCORBIDAE Ehrenberg, 1838
 1684 *Discorbis peruvianus* (d'Orbigny, 1839)
 1685 *Discorbis williamsoni* (Chapman and Parr, 1858)
 1686 *Discorbis* sp.
 1687 Family DISCORBINELLIDAE Sigal, 1952
 1688 *Discorbinella bertheloti* (d'Orbigny, 1839)
 1689 Family CIBICIDIDAE Cushman, 1927
 1690 *Cibicides aknerianus* (d'Orbigny, 1846)
 1691 *Cibicides dispars* (d'Orbigny, 1839)
 1692 *Cibicides refulgens* de Montfort, 1808
 1693 *Cibicides variabilis* (d'Orbigny, 1826)
 1694 *Cibicides* sp. 1
 1695 *Cibicides* sp. 2
 1696 *Cibicides* sp. 3
 1697 Family NONIONIDAE Schultze, 1854
 1698 *Nonion depressulus* (Walker and Jacob, 1798)
 1699 *Nonion pauperatum* Balkwill and Wright, 1885
 1700 *Nonionella auris* (d'Orbigny) = *Valvulina*
 1701 *auris* d'Orbigny, 1839.
 1702 *Melonis pompilioides* (Fichtel and Moll, 1798)
 1703 *Pullenia subcarinata* (d'Orbigny, 1839)
 1704 Family TRICHOHYALIDAE Saidova, 1981
 1705 *Buccella peruviana* (d'Orbigny, 1839) f. *campsi*
 1706 *Buccella peruviana* (d'Orbigny, 1839) f. *frigida*
 1707 *Buccella peruviana* (d'Orbigny, 1839) f. *typica*
 1708 Family ROTALIIDAE Ehrenberg, 1839
 1709 *Ammonia beccarii* (Linné, 1758)
 1710 Family ELPHIDIIDAE Galloway, 1933
 1711 *Elphidium alvarezianum* (d'Orbigny, 1839)
 1712 *Elphidium gunteri* Cole, 1931
 1713 *Elphidium lessonii* (d'Orbigny, 1839)
 1714 *Elphidium macellum* (Fitchel and Moll, 1798)
 1715 Suborder SPIRILLININA Hohenegger and Piller, 1975
 1716 Family SPIRILLINIDAE Reuss and Fritsch, 1861
 1717 *Patellina corrugada* Williamson, 1858

Appendix 3. : List of OSTRACODS

- 1721 Phylum CRUSTACEA Pennant, 1777
 1722 Class OSTRACODA Latreille, 1806
 1723 Order PODOCOPIDA Müller, 1894
 1724 Superfamily CYPRIDACEA Baird, 1845
 1725 Family PONTOCYPRIDIDAE Müller, 1894
 1726 *Argilloecia meridionalis* Brady, 1870
 1727 Superfamily CYTHERACEA Bair, 1850
 1728 Family CYTHERURIDAE Müller, 1894
 1729 *Oculocytheropteron burdwoodbankensis*
 1730 *Whatley and Cusmsinsky, 2002*
 1731 Family HEMICYTHERIDAE Puri, 1953
 1732 *Ambostracon bertelsae* (Sanguinetti et al., 1991)
 1733 *Austroaurila recurvirostrata* (Skogsberg, 1928)
 1734 *Austroaurila theeli* (Skogsberg, 1928)

- Family THAEROCYTHERIDAE Hazel 1987
Procythereis torquata Skogsberg, 1928
 Family XEXTOLEBERIDIDAE Sars, 1928
Xestoleberis sp.

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