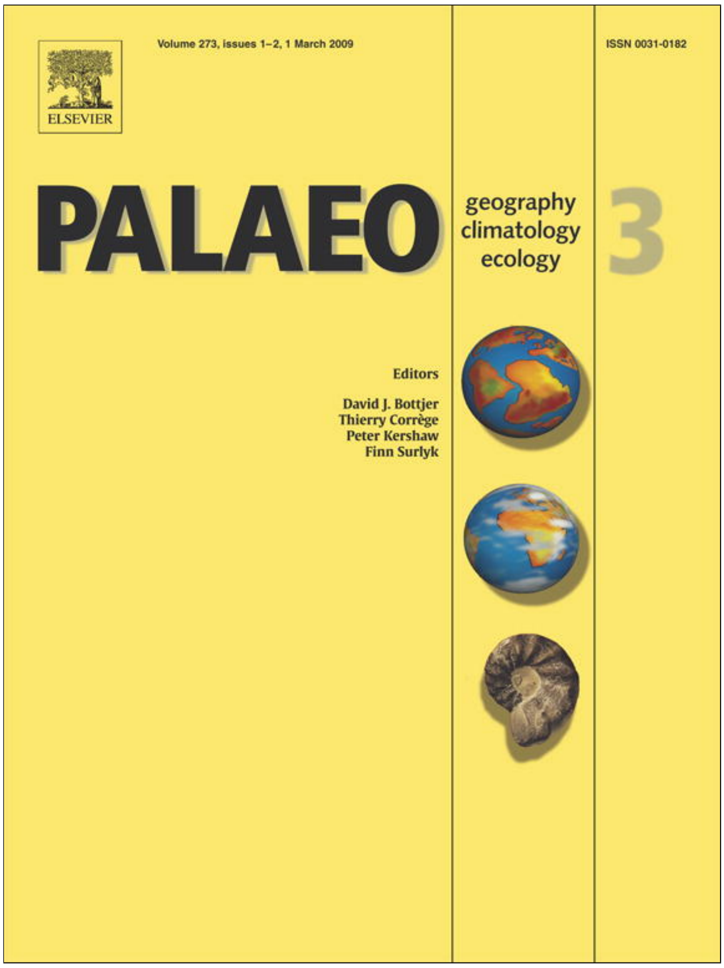
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Middle–Late Holocene palynology and marine mollusks from Archipiélago Cormoranes area, Beagle Channel, southern Tierra del Fuego, Argentina

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ABSTRACT

The palynology and marine mollusks of a marine sequence from Río Ovando (54° 51′ S, 68° 35′ W), Archipiélago Cormoranes, Beagle Channel, has been studied in order to reconstruct paleoenvironmental conditions during the Middle–Late Holocene. The dinoflagellate cyst assemblages from Río Ovando sequence reflect fjord (estuarine) environments close to terrestrial ice field, affected by glacier meltwater discharge, and characterized by short-term oscillations of sea-surface water parameters. The base of the section, which is dated at about ca. 4160 ^{14}C yr B.P. (4736 cal yr B.P.) (Palynological Subzone RO-2c), is characterized by a high species diversity of dinocyst and mollusks, and it is immediately followed by an interval (Palynological Subzone RO-2b) characterized by the presence of the *Echinidinium–Islandinium* complex and the monospecific *Mytilus* mollusk assemblage. This subzone registers an inverse correlation between *Nothofagus dombeyi* type and *Echinidinium–Islandinium* complex concentration values during ca. 4160 ^{14}C yr B.P. (4736 cal yr B.P.)–4064 ^{14}C yr B.P. (4540 cal yr B.P.), suggesting a variable climatic condition, probably related to Neoglacial episodes occurred in the southern Patagonia Andes during this interval. The pollen assemblages permit direct correlations with the onshore palynostratigraphy from southern of Tierra del Fuego. The high percentages of *Nothofagus dombeyi* type recorded throughout most of the profile strongly suggest the presence of a closed forest, confirming the existence of a variable, cool and wet climate for the Archipiélago Cormoranes area during the Middle–Late Holocene.

1. Introduction

The present Beagle Channel (54° 53′ S; 67° 00′–68° 40′ W), about 200 km long and 5 km wide, links the Atlantic and Pacific Oceans, separating the Isla Grande de Tierra del Fuego from the southern islands of the Fuegian archipelago (Fig. 1A). The Beagle Channel system is an inland passage in a complex web of channels, inlets and surrounding land masses that characterizes southern South America (Antezana, 1999). It is a drowned glacial valley, formerly occupied by a large outlet glacier from the Cordillera Darwin, the "Beagle Glacier". This valley was repeatedly glaciated, at least in two major episodes, during the "Lennox Glaciation" (Oxygen Isotopic Stage 6, >125 ka B.P.) and during the Last Glaciation named "Moat Glaciation" (Oxygen Isotopic Stage 2, 20–18 ka B.P.) (Rabassa et al., 2000). The Beagle Channel opened before 8200 ^{14}C yr B.P. and the marine environment was fully established at least by 7900 ^{14}C yr B.P. (Rabassa et al., 1986).

The Holocene marine transgression in southern Tierra del Fuego, according to Gordillo (1993), is represented by several discontinuous raised terraces along the northern Beagle Channel coast. Four informal terrace units have been recognized: Ancient Low Terrace, High Terrace, Middle Terrace and Recent Low Terrace, deposited ca. 8000, 6000, 5000–3000 and after 3000 yr B.P., respectively. These deposits are mostly sandy and gravely in grain-size, although clay-like sediments are found mainly in the westernmost sector of the Beagle Channel. The origin of these raised beaches appears related to tectonic uplift and/or isostatic recovery following deglaciation (Rabassa et al., 2000; Bujalesky et al., 2004).

There have been many contributions on the Holocene history of relative sea level change in Isla Grande de Tierra del Fuego: Codignotto, 1984; Porter et al., 1984; Rabassa et al., 1986, 1992, 2000; Isla, 1989; Rutter et al., 1989; Mörner, 1990; Bujalesky and González Bonorino, 1990; Bujalesky et al., 2004; Gordillo et al., 1992, 1993, 2005.

Occurrences of organic-walled dinoflagellate cysts, other aquatic palynomorphs and palynofacies from Holocene marine sediments in the northern coast of the Beagle Channel have been mentioned in Borromei et al. 1997; Borromei and Quattrocchio, 2001, 2007 and Grill et al., 2002. Mollusks are the most common remains in Holocene

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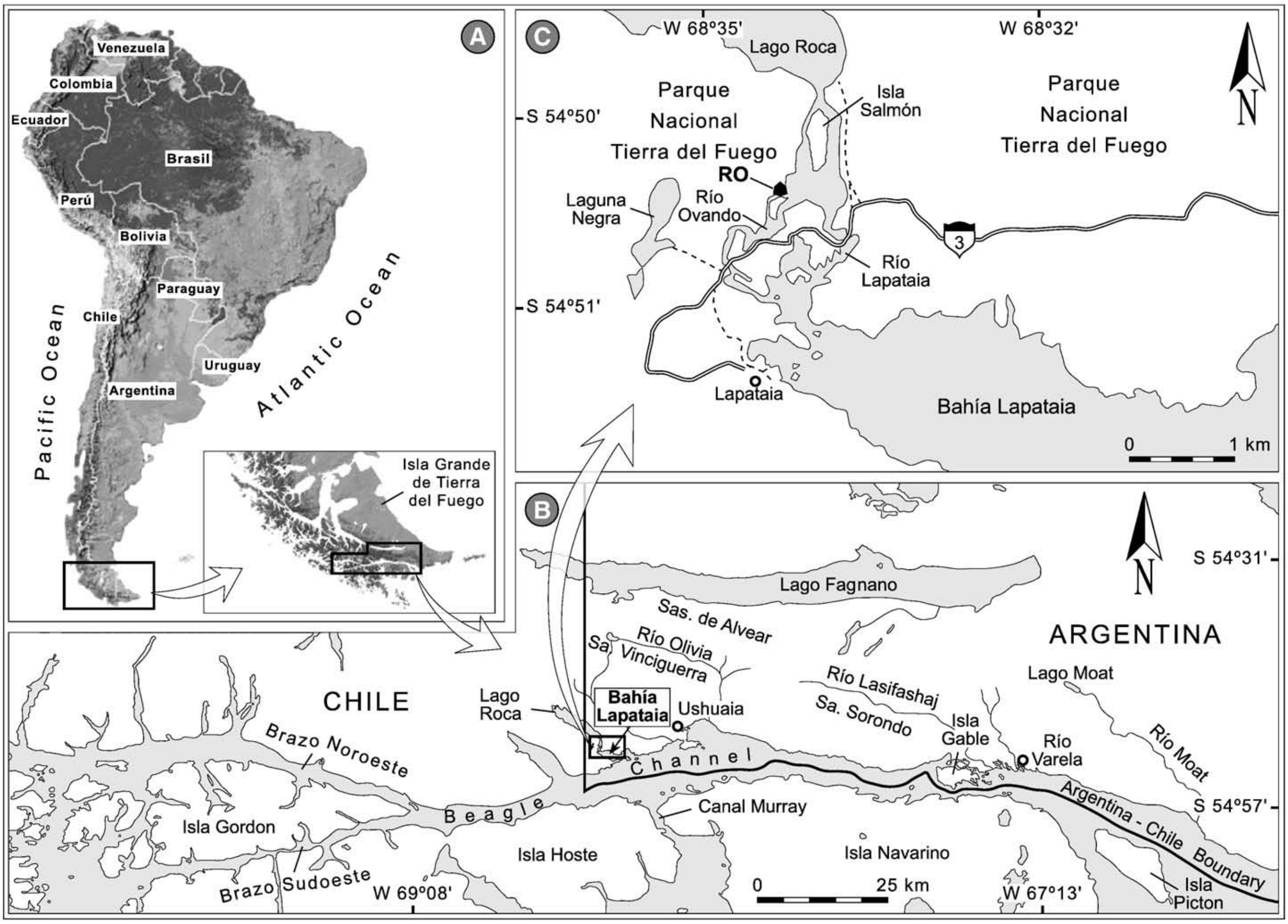

Fig. 1. A) Location map of the area; B) detail of the Beagle Channel region; C) detail of Archipiélago Cormoranes area.

marine raised beaches along the Beagle Channel (Gordillo, 1992). Prior to this work, special emphasis was placed on taphonomy of bivalves (Gordillo, 1992, 1999) and chitons (Gordillo, 2007), to aid paleoenvironmental reconstruction. These previous works analyzed the postmortem mechanical processes (i.e. disarticulation, fragmentation, orientation, abrasion, bioerosion, encrustation) affecting fossil remains, and their paleontological attributes (i.e. taxa composition, abundance, size frequency, mode of life), showing that – despite the bias in preservation due to taphonomic processes – these assemblages retain useful information pertaining to life habit and habitats of the marine benthos from which they are derived.

The aim of this paper is to characterize depositional paleoenvironments in the Archipiélago Cormoranes, Beagle Channel during holocene transgression, using palynological analysis and macrofossil paleoecology. We supplement this data with information on mollusk assemblages from the Río Ovando area, providing more complete knowledge on the environmental changes affecting the marine realm in this region during the Holocene. The comparison of the sediments found in the Río Ovando area with radiocarbon-dated marine deposits from Bahía Lapataia sites (Borromei and Quattrocchio, 2001, 2007) and Río Varela locality (Grill et al., 2002) will help in the interpretation of the paleoenvironmental conditions which took place during the Holocene relative sea level change into the Beagle Channel area, southern Tierra del Fuego.

2. Present climate and vegetation of Tierra del Fuego

The climate of Tierra del Fuego is determined by the belt of prevailing humid and cold westerlies. It is highly oceanic in the West and South parts of the archipelago and increasing continental towards the East and North. Mean summer isotherms increase northeastward from 9° to 12 °C. Precipitation decreases to the North and East. Mean annual rainfall in Ushuaia is 570 mm and less than 300 mm in Río Grande to the north (Heusser, 2003). The modern vegetation corresponds to the Fuego–Patagonian Steppe in the north, followed southward successively by the Subantarctic Deciduous Beech Forest and the Evergreen Beech Forest. They are characterized by three species of southern beech, *Nothofagus pumilio* (lenga), *Nothofagus betuloides* (guindo) and *Nothofagus antarctica* (ñire), which grows to an average altitudinal limit of 550–600 m a.s.l. (meters above sea level) and predominates where precipitation reaches between 400 and 800 mm/year. Magellanic Moorland occurs beyond the forest along the exposed outermost coast under conditions of increased precipitation, wind and poor drainage. High Andean Desert vegetation develops above treeline (600 m a.s.l.) in the Fuegian Andes until snowline is reached (Heusser, 2003).

3. General description of the area

3.1. Present physical setting at the Beagle Channel

The Beagle Channel is connected with the Pacific Ocean through Brazo Noroeste and Brazo Sudoeste surrounding Isla Gordon (Fig. 1B). Despite major connection to the Pacific Ocean at the mouth of the Beagle Channel, the shallow depth of its eastern end (west of Isla Gable) apparently restricts the inflow of subsurface Atlantic Ocean water (Gordillo et al., 2005). The narrowing (sill) of Archipiélago Gable

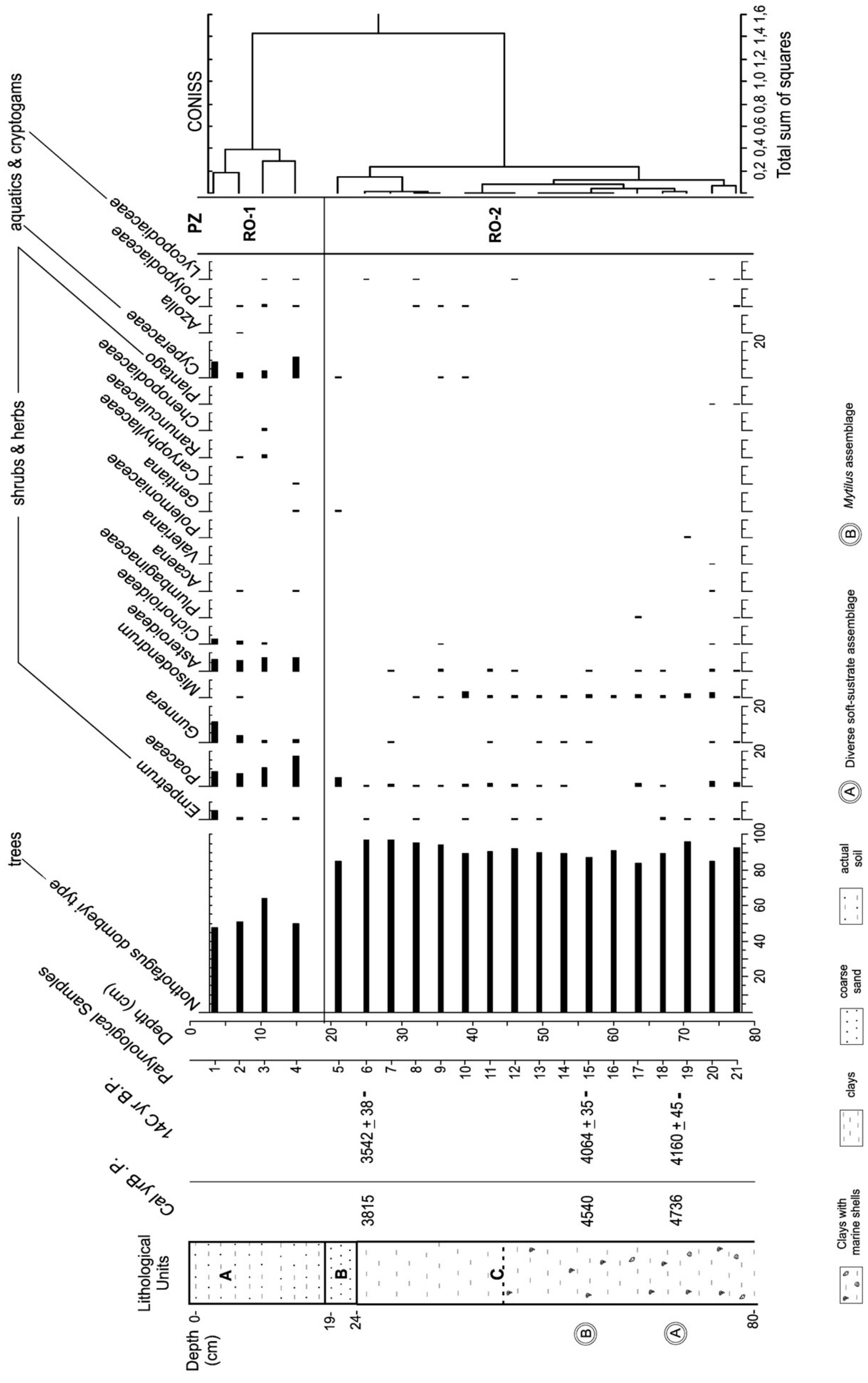

Fig. 2. Pollen/spore frequency (%) at Rio Ovando section. PZ: Palynological Zone.

not only modifies morphologically the fjord dynamics, but it also limits the relative effects of the eastern- and western-flowing tidal currents, and the gravity waves originate from the west (Isla et al., 1999).

The Beagle Channel waters are influenced by a strong freshwater discharge from precipitation and glaciers through the rivers during summer. The water column is strongly thermohaline stratified with water mixing at 12 m depth mainly during the summer season. The average sea-surface temperature is 6.5 °C with a maximum of 9 °C in January and a minimum of 4 °C in August. Sea-surface salinity varies from 27 to 33.5 PSU. Minimum values of salinity are obtained during summer depending on the volume of meltwater discharged into the channel. The Beagle Channel has ice-free conditions throughout the whole year (Iturraspe et al., 1989; Isla et al., 1999). The estuarine (fjord) dynamics are controlled by significant and seasonal fresh water sources, and by tidal flow from both the east (Atlantic) and the west (Pacific) (Isla et al., 1999).

3.2. Setting and stratigraphy of Río Ovando locality, Archipiélago Cormoranes

The Lago Roca–Lapataia valley (54° 50′ S, 68° 34′ W) is a glacial landscape formed by a series of low, rounded bed-rock hills, a typical ice-scoured terrain, surrounded by interconnected depressions filled with fresh-water lakes and ponds, peat bogs, or both. The entire area was partially submerged under the sea generating deep and narrow fjords and intricate archipelagos during the Holocene marine transgression, around ca. 8000 ^{14}C yr B.P. Probably, the marine advance had been started from the Canal Murray, east of Isla Navarino (Rabassa et al., 1986). The marine deposits are scattered along Bahía Lapataia up to the eastern shore of Lago Roca, including the Archipiélago Cormoranes area and, both margins of Río Ovando and Río Lapataia (Gordillo et al., 1992, 1993). The oldest marine radiocarbon dates for the Beagle Channel were obtained from shells of *Chlamys patagonica* from Lago Roca (7518+58 ^{14}C yr B.P.) and from shells of *Mytilus* sp. from Bahía Lapataia (8240+60 ^{14}C yr B.P.) (Rabassa et al., 1986, 2000). A reservoir effect somewhere between 630±70 yr at Beagle Channel (Albero et al., 1987) and 380±100 yr at Estrecho de Magallanes (Angiolini and Fernández, 1984) should be taken into consideration for those radiometric analyses performed on marine shells.

Lago Roca is connected to the Beagle Channel via fresh water branches: the Río Ovando and the Río Lapataia (Fig. 1C). The studied Holocene sequence (2.90 m a.s.l.) is located at the head of Río Ovando (54° 51′ S, 68° 35′ W). Three informal lithological units, separated by unconformities, are recognized (from base to top, Lithological Unit C to Lithological Unit A) (Fig. 2):

3.2.1. Lithological Unit C (80–24 cm)

Massive greenish grey clays. The unit contains marine shells in its lowermost part (80–45 cm). This unit was calibrated by radiocarbon dating. One, 4160+45 ^{14}C yr B.P. (Pta 7573) (Coronato et al., 1999) corresponds to the *Tawera gayi* shells (Coronato, pers. com), found in growth position, at 70 cm depth; the second, 4064±35 ^{14}C yr B.P., was obtained on organic matter at 58 cm depth. The last radiocarbon date, 3542±38 ^{14}C yr B.P. was also obtained on organic matter at 24 cm depth. The bottom of the profile was not observed because it was below water level.

3.2.2. Lithological Unit B (24–19 cm)

Greenish grey clayey coarse sand with pebbles.

3.2.3. Lithological Unit A (19–0 cm)

Present soil.

The ^{14}C ages were calibrated using INTCAL98 (Stuiver et al., 1998). Results span a calibrated age range between 3800 and 4700 years B.P. (Table 1).

4. Material and methods

A total of 21 samples were collected for palynological analysis from the base at 80 cm depth to the surface. The lithological Unit C was sampled continuously each 2 cm of sediment. All samples were processed for palynological analysis according to Heusser and Stock's techniques (1984). Following the procedure advocated by Dale (1976), the samples from marine units (Unit B and C) were treated with cold acids (HCl, HF) to preserve the organic-walled dinoflagellate cysts, and no oxidation and no acetolysis was applied in order to prevent the loss of more fragile protoperidiniacean cysts. All samples were stained with Safranin O, in accord with Stanley's technique (Stanley, 1966). Exotic spores (*Lycopodium*) were added to allow calculation of palynomorphs concentration per gram of dry weight of sediment (Stockmarr, 1971). The residue was sieved through a 10 µm mesh to concentrate the palynomorphs and mounted between a slide and cover slide in glycerin gel. The material was studied using a transmitted light microscope at 200× to 1000× magnification. The palynological slides are housed in the Laboratory of Palynology, Universidad Nacional del Sur, Bahía Blanca, Argentina, under the name UNSP followed by the denomination of the study section: RO (Río Ovando).

To evaluate the biosphere components, the frequencies (%) of trees, shrubs and herbs were based upon counts between 250 and 450 pollen grains; aquatic and cryptogam frequencies were from counts of total pollen and spores. To evaluate the terrestrial/marine environmental relationships and the sea level changes, the aquatic palynomorph (organic-walled dinoflagellate cysts, acritarchs, Chlorophyta algae, copepod egg-envelopes and test linings of foraminifera) frequencies (%) were based upon counts between 200 and 600 of total palynomorphs.

According to Heusser (1998), *Nothofagus betuloides*, *Nothofagus pumilio*, and *Nothofagus antarctica* are shown collectively as *Nothofagus dombeyi* type due to the impossibility of specific level differentiation. Another special case is *Empetrum rubrum* and *Gaultheria/Pernettya* (Ericaceae), being morphologically similar. The latter sometimes is possibly included together with *Empetrum* when its sculpture is not distinct.

The dinocyst taxonomical nomenclature used in this study conforms with the present in Rochon et al. (1999), Head et al. (2001) and Zonneveld (1997).

In our samples, the round, brownish, spiny dinoflagellate cysts recovered were grouped into "*Echinidinium–Islandinium* complex" because, in some cases, the determination at the species level was difficult due to the poor preservation and/or bad orientation (Fig. 3). The determination of fossil dinocyst taxa at specific level was made for comparison with modern forms from surface samples of Beagle Channel and at the moment they are reason of study by one of the authors (M.S.C.). In our analysis, specimens of *Brigantedinium simplex* Wall 1965 and *Brigantedinium cariacoense* Wall 1967 are grouped under the name of *Brigantedinium* spp. when the archeopyle was not observed due to orientation.

Algae assemblages recovered in the Río Ovando section include the groups Prasinophyceae, Zygnemataceae and Chlorococcales, among

Table 1
AMS ^{14}C dates and calibrated ages of selected samples from the Río Ovando sequence with the maximum and minimum 2σ ranges

Sample	Depth (cm)	^{14}C age BP	Calendar year BP	Maximum 2σ B.P.	Minimum 2σ B.P.	Laboratory reference	Material dated
6	24–26	3542±38	3815	3923	3707	AA-75400	Organic matter
15	58–60	4064±35	4540	4645	4435	AA-69513	Organic matter
19	70–72	4160±45	4736	4863	4435	Pta-7573	Valves

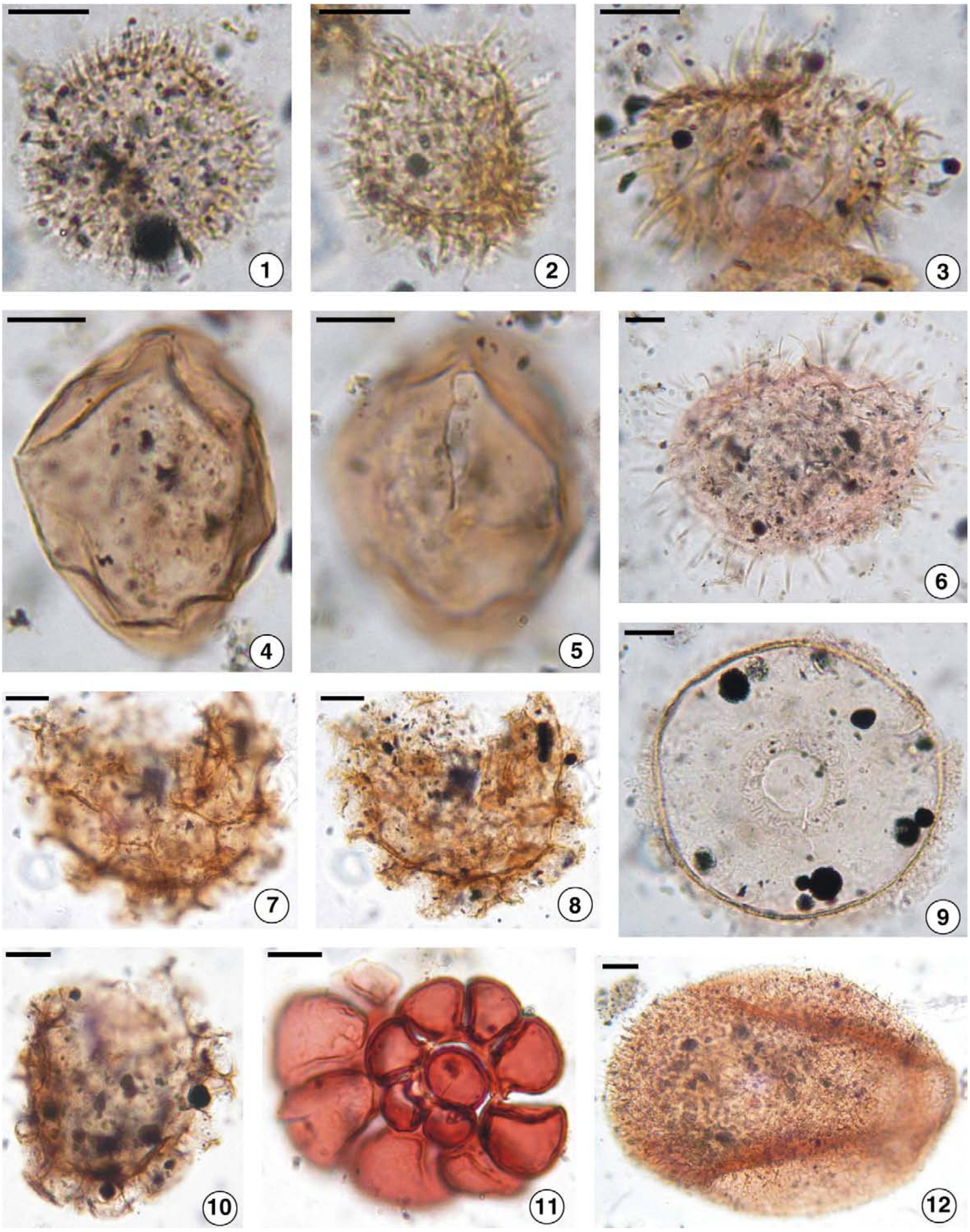

Fig. 3. Scale bar is 10 µm.1–3. *Echinidinium–Islandinium* complex. 1. UNSP RO 1968: C17/1. 2. UNSP RO 1966: W59. 3. UNSP RO 1972: X22. 4, 5. *Brigantedinium simplex*, UNSP RO 2037: Q28. 4. Apical view, low focus. 5. Apical view, high focus. 6. *Selenopemphix quanta*, UNSP RO 1972b: M38/2. 7, 8, 10. Polykrikos kofoidii. 7, 8. UNSP RO 1972b: F37/1. 10. UNSP RO 1972c: J50/1. 9. *Halodinium sp.*, UNSP RO 1972c: R13 11. Foraminiferal test-lining, UNSP RO 1972d: G34/4. 12. Copepod egg-envelope, UNSP RO 1972c: G14/2.

others. In this paper we make a general mention; the details about algae associations will be present in a next work.

Cluster analysis using Edwards & Cavalli–Sforza distance (Program TILIA, E. Grimm, 1991) was applied to the fossil palynological assemblages. In this analysis, taxa with percentages below 1% were excluded.

The pollen/spore frequency (%) (Fig. 2) and total palynomorph frequencies (%) with terrestrial and aquatic palynomorph concentrations (Fig. 4) at Río Ovando section are represented. From units B and C, the percentage values and the numbers of organic-walled dinoflagellate cysts, acritarchs and zoomorphs per gram of sediment recovered throughout the unit is given in Table 2.

Mollusks were taken from exposures of natural cutting at the head of the Río Ovando, on its left margin at two levels (basal bed and 50 cm depth). Large specimens were separated from the sediment matrix in the field. The smaller specimens (<20 mm) were sorted in the laboratory from a bulk sediment sub-sample of 0.05 m^3, under a stereoscopic microscopy. Mollusks were identified at the lower

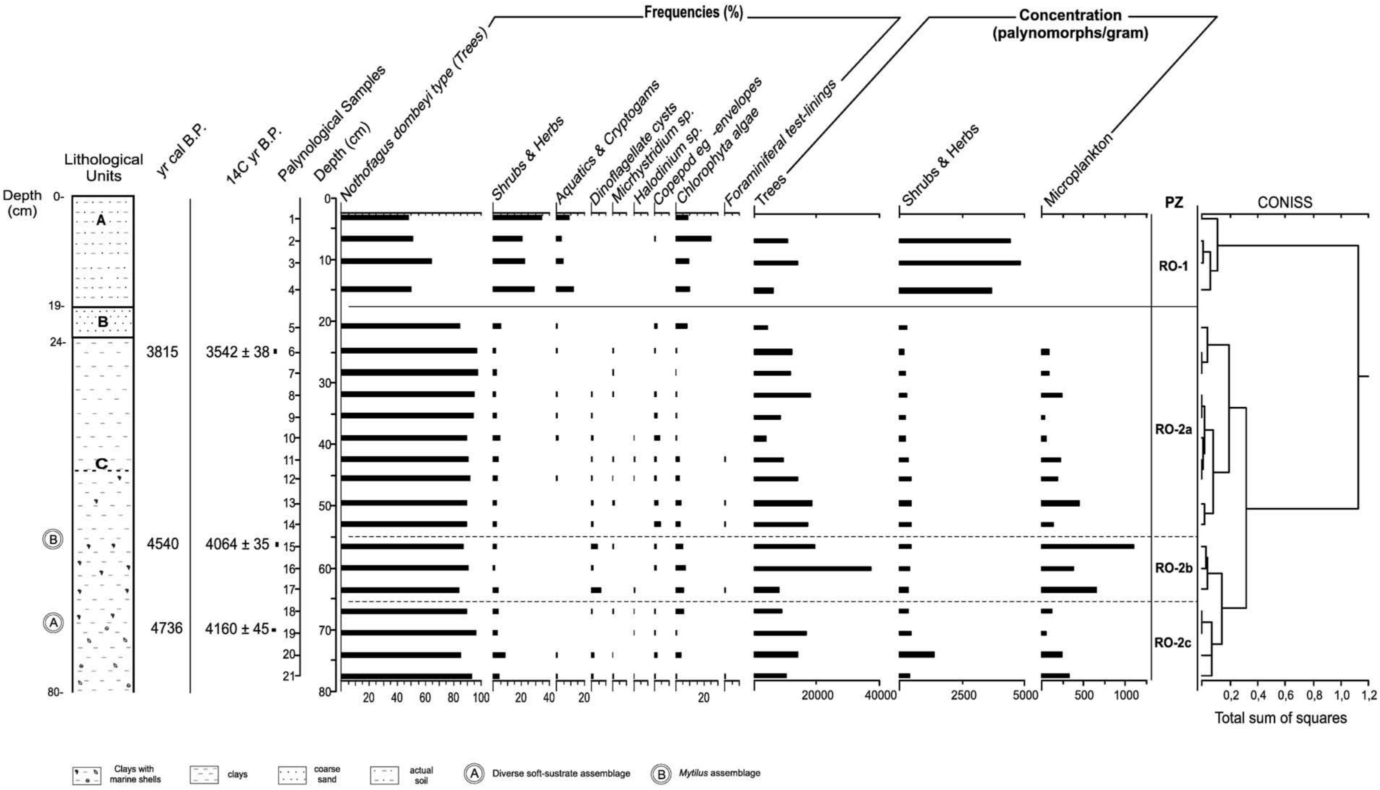

Fig. 4. Palynomorph frequencies (%) and concentration values at Río Ovando section. PZ: Palynological Zone.

taxonomic level possible. A preliminary faunal list was presented in Gordillo et al. (2005). However, the generic placement or nominal species of some taxa (especially small-sized species) are still under revision. Specimens were figured using a scanning electron microscope (LEO 1450VP, backsattered electron image) or a binocular microscope (LEICA MZ). The material examined here is deposited at the Centro de Investigaciones Paleobiológicas, Universidad Nacional de Córdoba (CEGH-UNC).

4.1. Ecology of dinoflagellate assemblages

Dinoflagellates, unicellular planktonic organisms, inhabit surface-waters in a wide range of marine environments. The abundance and distribution of dinoflagellate cysts (hypnozygotes or resting spores) depend on the primary production and the physico-chemical conditions (temperature and salinity) in surface water of the photic zone (de Vernal et al., 1993). During major sea-level changes, however, this steady state of associations in surface waters and associated sediments is exposed to disturbances from various dynamic processes like erosion, winnowing of sediments, intrusion and mixing of different water masses, which affect the regional microplankton associations within the water column and associated sediments respectively (Prauss, 2000).

In our samples, among the Peridiniales taxa, specimens of *Islandinium minutum* and *Echinidinium granulatum*, *E. delicatum* and *E.* spp. were grouped together into *Echinidinium–Islandinium* complex. *Islandinium minutum* is the more specific taxa of shelf assemblages of the Arctic Ocean, including polynyas (Kunz-Pirrung et al., 2001). It is an euryhaline taxon dominating assemblages from the continental margins where summer temperatures rarely exceeding 7 °C ranging from −2 to 5 °C and salinity varies between 17 to 34 PSU. The duration of sea-ice cover in the Arctic Ocean is greater than 8 months per year (de Vernal et al., 2001; Head et al., 2001). *Echinidinium granulatum*, *E. delicatum* and *E.* spp. occur in subtropical to tropical regions with temperature and salinity ranges of 13 to 29 °C and 25 to 36, respectively (Marret and Zonneveld, 2003). However, recently, Radi and de Vernal (2004) documented *E. granulatum* for surface sediment samples from the northeastern Pacific, with a temperature range as low as of 4 to 19 °C. Highest relative abundances of *Echinidinium* are also found in eutrophic environments related with upwelling and river discharged (Zonneveld, 1997).

Brigantedinium is a cosmopolitan taxon especially in epicontinental environments. It probably is an opportunistic genus (de Vernal et al., 2001), often dominating low-salinity environments and it is presence suggests high concentrations of nutrients in the surface waters owing to freshwater input from glacier meltwater (Grøsfjeld et al., 1999).

Selenopemphix quanta shows a preference for the temperate to subpolar domain and occurs mainly in neritic environments where salinity can be relatively low (de Vernal et al., 2001). It seems to be more adapted to higher summer temperature between 8 and 14 °C and salinity between 23 and 31 PSU (Kunz-Pirrung, 2001).

Cysts of *Pentapharsodinium dalei* occur from tropics to arctic areas and coastal to deep-sea sites. This species is distributed within a wide range of temperatures between −2.1 and 29.6 °C and salinity between 21.3 and 36.7 PSU (Marret and Zonneveld, 2003).

Among the Gymnodiniales, *Polykrikos kofoidii* is a tropical to subtropical species adapted to temperatures between 25 and 29 °C and salinity between 31 and 36 PSU. It has been described from surface samples around the Japanese Archipelago (Matsuoka, 1985) and is generally documented from tropical to subtropical coastal regions of the major upwelling areas. Radi et al. (2001) documented this species for the Bering and Chukchi seas, suggesting temperatures colder than previously recorded. *Polykrikos schwartzii* is a cold temperate to subtropical species distributed within a broad temperature range between −0.9 and 27.5 C and salinities exceeding 28.5 PSU. It occurs in a wide range of environments from coastal to open oceanic and oligotrophic to eutrophic (Marret and Zonneveld, 2003).

The gonyaulacalean cysts include cosmopolitan taxa such us *Operculodinium* cf. *centrocarpum* recorded in coastal and deep-sea environments and tolerant of large fluctuations in temperature and salinity, and *Spiniferites* spp., which is usually found in neritic environments from tropical to polar regions (Matthiessen, 1995; de Vernal et al., 2001).

5. Results

5.1. Palynological assemblages

Based on cluster analysis, two palynological zones spanning the full sequence are distinguished at Río Ovando section according to the pollen assemblages. The Palynological Zone RO-1 is restricted to Lithological Unit A, and the Palynological Zone RO-2 spans Lithological Unit B and Lithological Unit C (Fig. 2). Based on dinoflagellate cyst assemblages, the Palynological Zone RO-2 can be divided into three palynological subzones (Subzones RO-2a, RO-2b and RO-2c) (Fig. 4). In order, from the lower to the upper part of the sequence, they are:

5.1.1. Zone RO-2

Is dominated by *Nothofagus dombeyi* type (84–97%). Shrubs and herbs (Poaceae, *Misodendrum*, *Empetrum*, *Gunnera*, Asteroideae and Cichorioideae) are found with percentage values of up to 8.3%. Tree pollen concentration varies between 3811–37626 grains/gram and herb and shrub pollen concentration between 160–1390 grains/gram (Fig. 4).

5.1.1.1. Subzone RO-2c. The microplankton content is low. The dinocyst assemblage represented by *Echinidinium–Islandinium* complex, *Brigantedinium* spp., *Polykrikos kofoidii* Chatton, 1914, *Polykrikos schwartzii* Bütschli, 1873, *Selenopemphix quanta* Bradford, 1975 and *Operculodinium* cf. *centrocarpum* make up <1% each one. Other microplanktonic constituents are present with low values, such as acritarchs (*Micrhystridium* spp. and *Halodinium* sp.), reaching up to 0.4% and copepod egg-envelopes (up to 1.4%). Chlorophyta algae association are present with values between 0.6 and 5.8%. The highest diversity of dinoflagellate cysts (7 taxa) of this section is registered at sample 21 (Table 2).

5.1.1.2. Subzone RO-2b. The increase of aquatic palynomorph frequencies reaches maximum values at samples 17 and 15 characterized by dinoflagellate cysts of *Echinidinium-Islandinium* complex (up to 6.3%). Acritarchs (*Micrhystridium* spp. and *Halodinium* sp.) and copepod egg-envelopes are recorded with low percentage values (<1% each one). Algae group is registered with values up to 6.6%. The highest abundance of marine palynomorphs is recorded in this subzone. Maximum values of dinocysts concentration are registered at sample 17 (592 dinocysts/gram) and sample 15 (965 dinocysts/gram) (Table 2).

5.1.1.3. Subzone RO-2a. Microplankton frequencies represented by dinoflagellate cysts of *Echinidinium–Islandinium* complex, *Selenopemphix* spp., *Brigantedinium* spp., cf. *Pentapharsodinium dalei* Indelicato & Loeblich III, 1986 and *Spiniferites* spp. decrease (<1% each one). Meanwhile, copepod egg-envelopes frequencies increase (near to 4%) and acritarchs, mainly *Micrhystridium* spp., are present with <1%. The algae association is registered with percentages between 0.3 and 8.1%.

The dinoflagellate cysts show more diversity (6 taxa) and lower concentration values (27–251 dinocysts/gram) than those in the former subzone (Subzone RO-2b) (Table 2). The samples 14 and 13 show the highest values of this subzone of marine palynomorphs, mainly copepod egg-envelopes (855 and 564 specimens/gram, respectively) accompanied by acritarchs (188 acritarchs/gram).

Table 2
Aquatic palynomorphs diversity and concentration values at Río Ovando section

Aquatic palynomorphs										
	Dinocysts									
Palynological samples	Palynological Zones	*Brigantedinium simplex*	*Brigantedinium* spp.	*Echinidinium-Islandinium* complex	*Operculodinium* cf. *centrocarpum*	cf. *Pentapharsodinium dalei*	*Polykrikos kofoidii*	*Polykrikos schwartzii*	*Selenopemphix quanta*	*Selenopemphix* spp.
1	RO-1	–	–	–	–	–	–	–	–	–
2		–	–	–	–	–	–	–	–	–
3		–	–	–	–	–	–	–	–	–
4		–	–	–	–	–	–	–	–	–
5	RO-2a	–	–	–	–	–	–	–	–	–
6		–	–	–	–	–	–	–	–	–
7		–	–	–	–	–	–	–	–	–
8		–	–	0.6	–	–	–	–	–	–
9		–	–	–	–	0.3	–	–	–	–
10		–	–	0.4	–	–	–	–	–	–
11		–	–	0.6	–	–	–	–	–	–
12		–	–	0.6	–	–	–	–	–	–
13		–	–	0.9	–	–	–	–	–	0.3
14		0.4	–	–	–	–	–	–	–	0.4
15	RO-2b	–	–	4.3	–	–	–	–	–	–
16		–	–	0.9	–	–	–	–	–	–
17		–	–	6.3	–	–	–	–	–	–
18	RO-2c	–	–	0.4	–	–	–	–	–	–
19		–	–	–	–	–	–	–	–	–
20		–	0.4	0.7	0.2	–	–	–	–	–
21		–	0.3	0.3	0.1	–	0.2	0.1	0.1	–

5.1.2. Zone RO-1

Is characterized by increase of Poaceae (7–17%), Asteroideae (7–8%) and Cyperaceae (3–11%) accompanied by *Gunnera* (1–2%), *Empetrum* (up to 1%) and Cichorioideae (<3%). *Acaena*, *Misodendrum* and Ranunculaceae, among others, are also present (1% each one). Aquatic palynomorphs are represented by algae group with values up to 25.1%. Although *Nothofagus dombeyi* type frequencies decrease (49–64%), tree pollen concentration values increase to 6353–14045 grains/gram. The shrub and herb concentration values also increase to 3689–4780 grains/gram (Fig. 4).

5.2. Mollusk marine assemblages

The Río Ovando area is very rich in fossil remains. These marine deposits contain large proportion of whole, well-preserved shells. A great number of specimens retain their original color and unaltered sculpture. Bivalves normally occur as whole joined valves, oriented in life position (e.g., Laguna Verde site, Río Ovando site; Gordillo, 1999), or horizontally and randomly oriented within the bed. A minor proportion of shells show an abraded surface and damaged margins, indicating that the skeletal assemblage has been transported some distances. Bivalves contribute most of the biomass, although gastropods exhibit the highest richness. Chitons are also present in low numbers.

Mollusks from the head of Río Ovando, left margin sector, yield two distinct assemblages:

5.2.1. Diverse soft-substrate assemblage

This mollusk assemblage (Assemblage A) is restricted to the basal bed at Río Ovando, which has been correlated to sections dated to 4160 ^{14}C yr B.P (4736 cal yr B.P). It is composed of a great number of species (Fig. 5), belonging to the venerids (*Tawera gayi*, *Venus antiqua*) and myoids (*Hiatella solida*). Among gastropods, the more common taxa are the muricids (*Trophon geversianus*, *Xymenopsis muriciformis*) and the buccinid (*Pareuthria plumbea*). Within the small sized mollusks a great number of taxa as rissoid forms, *Laevilitorina*, *Neolepton*, and the carditids *Carditella naviformis* and *Cyclocardia compresa*, among others, characterize this assemblage.

5.2.2. The Mytilus assemblage

Mollusk Assemblage B is derived from a rather homogeneous massive greenish clay at 50 cm. The assemblage is almost monospecific, being characterized by abundant epifaunal *Mytilus chilensis*, and less common *Hiatella solida*.

6. Paleoecological and paleoenvironmental interpretations

6.1. Pollen and spore assemblages

The palynological analysis at Río Ovando section shows predominance of terrestrial palynomorphs (pollen and spores) over aquatic palynomorphs (dinoflagellate cysts, acritarchs and zoomorphs) (Fig. 4). Pollen and spores in marine sediments constitute long distance fluvial and/or atmospheric inputs originating from the terrestrial vegetation of adjacent lands (in de Vernal et al., 1993). Based on pollen studies of surface samples from Tierra del Fuego, the *Nothofagus* pollen has a great atmospheric dispersion. It is carried, often in large quantities, far from its point of origin (Heusser, 1989a). In nearshore regions, pollen and spore records potentially reflect the regional vegetation on littoral at the time of their deposition, although their records are often overprinted with a coastal signal (Borromei and Quattrocchio, 2007).

Spectra from Río Ovando record (Fig. 2) are used to identify regional changes of vegetation and make to cronostratigraphic correlations with the previous palynostratigraphy based on pollen assemblages in the area (Heusser, 1989a, 1998). The significant percentages of *Nothofagus dombeyi* type recorded throughout most of the profile strongly suggest the presence of a closed forest, confirming the existence of a cool and wet climate for the Archipiélago Cormoranes area during the Middle–Late Holocene.

The identified Palynological Zone RO-2 with highest percentages of *Nothofagus dombeyi* type, correlated with the Pollen Zone 1 (5000–0 yr BP) of Heusser (1989a), resemble the modern Deciduous Beech Forest with annual precipitation varying between 500 and 800 mm, and summer temperature averaging 8–9 °C.

The decrease of *Nothofagus dombeyi* type and increase of herb and shrub percentages in the Palynological Zone RO-1, along with increase of brackish chlorophyta (Prasinophyceae) reflect the development of

			Acritarchs			Zoomorphs			Aquatic palynomorphs diversity
cf. *Spiniferites* spp.	Dinocysts/gram	Diversity (taxa number)	*Halodinium* sp.	*Micrhystridium* spp.	Acritarchs/gram	Copepod egg-envelopes	Foraminiferal test-linings	Zoomorphs/gram	
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	0.3	–	72	1
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	
–	–	–	–	–	–	1.7	–	91	1
–	–	–	–	0.6	80	0.3	–	40	2
–	–	–	–	0.6	79	–	–	–	1
–	118	2	–	0.6	118	0.9	–	177	4
–	27	1	–	–	–	1.9	–	165	2
0.4	35	3	0.4	–	17	3.2	–	139	5
–	64	2	0.9	0.6	160	1.2	0.3	160	6
–	94	2	–	0.6	94	1.2	–	187	4
–	251	3	–	0.9	188	2.4	0.3	569	6
–	143	2	–	–	–	4.1	0.4	855	4
–	965	2	–	0.6	129	0.9	–	193	4
–	376	2	–	–	–	0.9	–	376	3
–	592	2	0.6	–	56	–	0.6	56	4
–	36	2	0.4	0.4	73	0.4	–	36	5
–	–	–	0.3	–	56	0.6	–	111	2
–	212	4	–	0.2	30	1.4	–	242	6
–	110	7	0.1	0.4	55	0.7	0.1	82	11

open beech woodland communities with patches of grass and sedges over adjacent lands associated with a marginal marine influence.

6.2. Marine microplankton assemblages

The dinoflagellate assemblages in the fossil sequence are characterized by low species diversity (9 identified taxa) and low concentration values (Table 2). The Peridiniales dominate over Gonyaulacales taxa suggesting inner neritic environments (de Vernal and Giroux, 1991).

The RO-2c subzone, at the base of the section, is characterized by the highest species diversity (7 taxa) and low dinocyst concentrations (36–212 dinocyst/gram). The dinocyst assemblage shows co-dominance of *Echinidinium–Islandinium* complex and *Brigantedinium* spp. accompanied by *Polykrikos kofoidii*, *Polykrikos schwartzii*, *Operculodinium* cf. *centrocarpum* and sparse occurrence of *Selenopemphix quanta*. The dinocyst assemblage suggests marginal marine environments, low to moderate salinity and reflects high concentrations of nutrients in the surface waters probably due to freshwater input from glacier meltwater.

The RO-2b subzone shows not only the dominance of *Echinidinium–Islandinium* complex but also the greatest cyst abundance and lowest species diversity. This assemblage might indicate the occurrence of monospecific dinocyst assemblage, characterized by "opportunistic species", suggesting the high freshwater input may be related to glacier meltwater. The increase of fresh- to brackish water chlorophyta algae confirms this scenario. The low diversity of microplankton associations may be indicative of stressed, restricted conditions with often unstable salinities (in Gorin and Steffen, 1991). Also, sediments deposited under low-oxygen conditions show reduced cyst diversities and high abundance of one species (Sluijs, 2006).

The RO-2a subzone is characterized by an increase in species diversity (6 taxa) and decrease in dinocyst concentrations. The *Echinidinium–Islandinium* complex is accompanied by *Selenopemphix* spp., *Brigantedinium* spp., cf. *Pentapharsodinium dalei* and *Spiniferites* spp. This dinocyst assemblage suggests environmental conditions comparable to those of subzone RO-2c. The record of copepod egg-envelopes could reflect geographical variations in the nutrient regime of the euphotic zone (Van Waveren, 1994).

6.3. Preservation and paleoecology of marine mollusks

The assemblage A is dominated by filter-feeding shallow infaunal (*Venus antiqua*) and semi-infaunal (*Tawera gayi*, *Hiatella solida*) burrowers, and vagrante epifaunal elements, with feed on carrion (i.e., *Pareuthria plumbea*) or prey upon bivalves (i.e., the predators *Trophon geversianus* and *Xymenopsis muriciformis*).

In the assemblage B, *Mytilus chilensis* is a suspension feeder that most probably lived bysally attached to hard substrates in the area. A great number of these specimens were found articulated, but their shells exhibit selective dissolution that facilitates its separation in layers resulting in broken articulated specimens. A less abundant species, *Hiatella solida*, is eurytopic (i.e., able to adapt to a wide range of environmental conditions) living bysally attached as epifauna, or partially buried as infauna. These shells are found articulated in this assemblage.

7. Discussion and conclusions

In the hinterland of the Archipiélago Cormoranes area, late Holocene vegetation conforms to the general paleoclimate evolution in southern Tierra del Fuego. The vegetation and climatic setting of southern Tierra del Fuego over the Late Holocene, as expressed by the pollen data (Heusser, 1989a, 1998, 2003; Borromei, 1995; Borromei et al., 2007, this paper), is characterized by the dominance of beech forest under a variable, cooler and more humid climate with increased storminess and cloud cover. During the Holocene, a range of shallow benthic paleocommunities occupied the northern coast of the Beagle Channel (Gordillo, 1999; Gordillo et al., 2005). The postglacial mollusks from the Beagle Channel agree in taxa composition and mollusk assemblages with the fauna living today in the region. Thus, climatic conditions maintain stable enough to allow the survival of the same marine faunistic associations, which have a wide ecological range equivalent to taxa living today (Gordillo, 1999).

Most of the present dinocyst taxa have a widespread ecological distribution, but the dinoflagellate cyst assemblages recorded in Río Ovando section (*Echinidinium–Islandinium* complex, *Polykrikos kofoidii*, *Polykrikos schwartzii*, *Brigantedinium simplex*, *Brigantedinium* spp.,

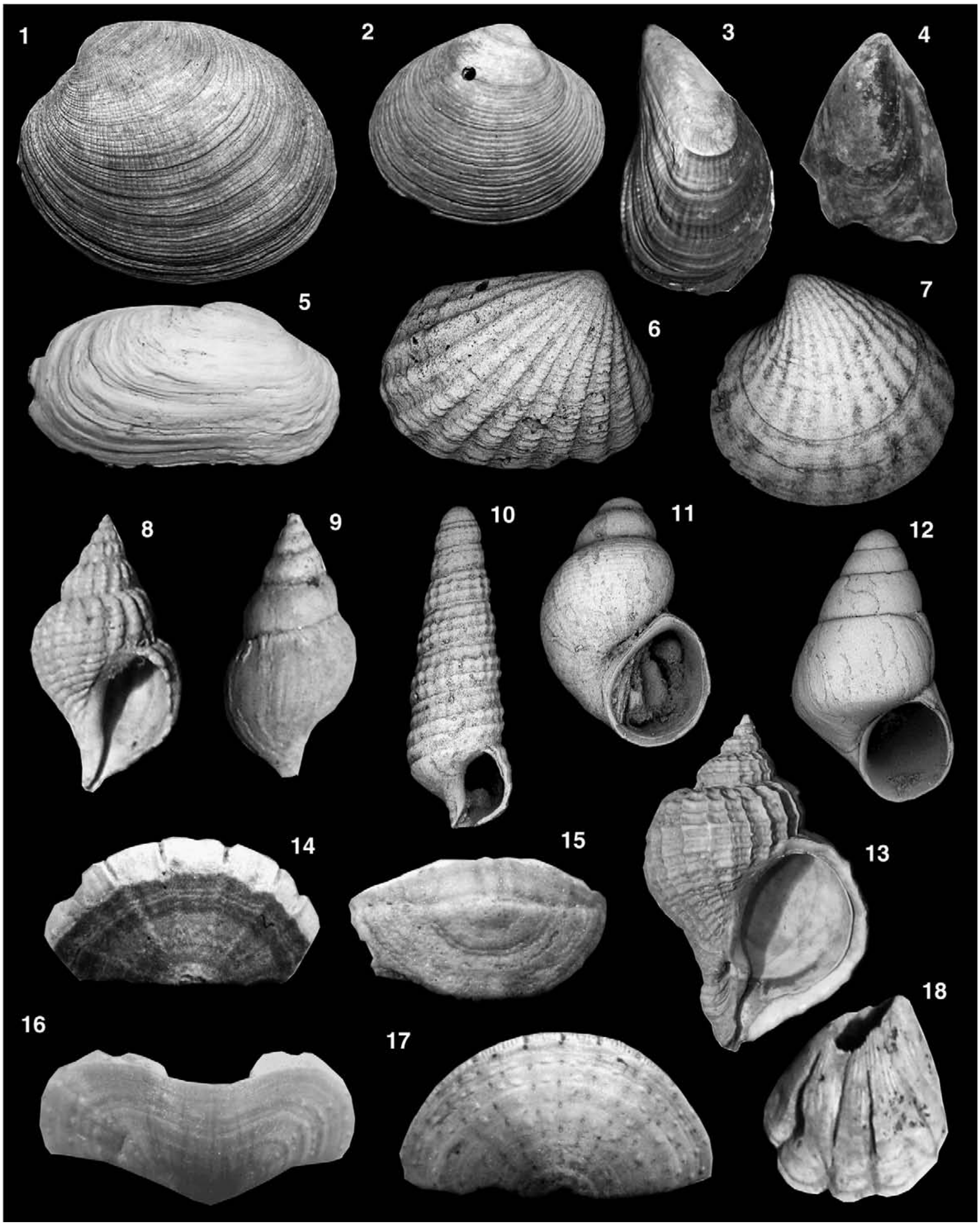

Fig. 5. Most characteristic mollusks and associated fauna collected at the heads of the Río Ovando. A. Bivalves: 1. *Venus antiqua* King and Broderip, 1832 (*L*=71 mm), left valve, CEGH-UNC 23399. 2. *Tawera gayi* (Hupé in Gay, 1854) (*L*=35 mm), right valve, CEGH-UNC 23401. 3. *Aulacomya atra* (Molina, 1782) (*H*=62 mm), right valve, CEGH-UNC 22674. 4. *Mytilus chilensis* Hupé in Gay, 1854 (*H*=32 mm, broken shell, left valve, CEGH-UNC 23404. 5. *Hiatella solida* (Sowerby, 1834) (*L*=42 mm), right valve, CEGH-UNC 23408. 6. *Carditella naviformis* (Reeve, 1843) (*L*=4 mm), right valve, CEGH-UNC 23296. 7. *Cyclocardia compresa* Reeve, 1843 (*L*=3 mm), left valve, CEGH-UNC 23289. B. Gastropods: 8. *Xymenopsis muriciformis* (King and Broderip, 1832) (*H*=20 mm), CEGH-UNC 22714. 9. *Pareuthria plumbea* (Philippi, 1844) (*H*=21 mm), CEGH-UNC 23403. 10. *Ataxocerithium pullum*? (*H*=4 mm), CEGH-UNC 23307. 11. *Onoba* sp. (*H*=3 mm), CEGH-UNC 23305. 12. *Eatoniella* sp. (*H*=2 mm), CEGH-UNC 23304. 13. *Trophon geversianus* (Pallas, 1769) (*H*=58 mm), CEGH-UNC 23406. C. Chitons: 14. *Plaxiphora aurata* (Spalowsky, 1795) (*L*=5 mm), head valve, CEGH-UNC 23331. 15. *Callochiton puniceus* (Couthouy MS, Gould, 1846 (*L*=3 mm), tail valve, CEGH-UNC 23320. 16. *Tonicia lebruni* de Rochebrune, 1827 (*L*=6 mm), intermediate valve, CEGH-UNC 23343. 17. *Tonicia lebruni* de Rochebrune, 1827 (*L*=4 mm), head valve, CEGH-UNC 23332. D. Other invertebrates: 18. Cirriped indet. (*W*=15 mm), CEGH-UNC 23402. Dimensions (in mm). *L*=length; *H*=height; *W*=maximum width. SEM photographs (6, 7, 10, 11 and 12).

Selenopemphix quanta, *Selenopemphix* spp., *Operculodinium* cf. *centrocarpum*, cf. *Pentapharsodinium dalei* and cf. *Spiniferites* spp.) have a special interest because constitutes the first mention of these association at high latitudes of the South America. Their composition is comparable to those of modern assemblages from the Laptev Shelf in the eastern Arctic (Kunz-Pirrung, 2001) and from Canadian Arctic Archipelago, including polynyas (Mudie and Rochon, 2001), that is strongly influenced by the freshwater input of the rivers in summer.

The present dinocyst assemblages reflect fjord (estuarine) environments close to terrestrial ice field affected by glacier meltwater discharge with anomalously low salinity in the Archipiélago Cormoranes (Lago Roca–Bahía Lapataia area). These assemblages show variations in a wide range of temperatures from cold to tropic conditions, so it is difficult determine climatic variability linked to decline of temperature.

At the base of the Río Ovando section, the RO-2c subzone is characterized by the highest species diversity and low dinocyst concentrations. This dinocyst assemblage suggests marginal marine environments with low to moderate salinity and reflects high concentrations of nutrients in the surface waters owing to freshwater input from glacier meltwater. Mollusk data support that during this interval (under relatively warmer conditions) a major expansion of the fauna took place, and further diversification of mollusk assemblages was characterized by the dominance of venerids and the appearance of other families or groups (e.g., carditids), indicating shift towards present day conditions.

Throughout the Río Ovando section, *Nothofagus dombeyi* type concentration values show variability (Fig. 4). These forest fluctuations appear to bear a relationship with fluctuations of the main group of dinoflagellate cysts, the *Echinidinium–Islandinium* complex, as can be seen in the Palynological Subzone RO-2b (Fig. 4; Table 1) after ca. 4160 ^{14}C yr B.P. (4736 cal yr B.P.) and before 4064 ^{14}C yr B.P. (4540 cal yr B.P.). We interpret the inverse correlation of *Nothofagus* concentration and *Echinidinium–Islandinium* complex concentration as a result of a rapid climatic variability related to changes in temperature and precipitation.

The replacement from a diverse fauna of suspension-feeding mollusks characterized by the presence of venerids and other mollusks -including bivalves, gastropods and chitons (Assemblage A), to an almost monospecific fauna with taxa (i.e., *Mytilus* and *Hiatella*) (Assemblage B) tolerant to low or variable salinity suggest a major seasonal input of freshwater (from rivers discharging into the area and /or the ice melting).

This climatic variability, lasting ca. 100 ^{14}C yr B.P., might be correlated with Neoglacial episodes occurred in the southern Patagonia Andes Range (Mercer, 1982). According to Heusser and Streeter (1980) intervals of relatively low temperature appear to have coincided with periods when precipitations were significantly higher than today during Late Holocene glacier advances (see Rabassa and Clapperton, 1990).

Upward in the profile, between 4064 ^{14}C yr B.P. (4540 cal yr B.P.) and 3542 ^{14}C yr B.P. (3815 cal yr B.P.), the intervals with low concentration values of trees along with scarce occurrence of marine palynomorphs might be associated with a regressive event.

Evidence for several Neoglacial readvances was observed in the cirques of the hanging lateral valleys in the Eastern Fuegian Andes according to the geomorphological studies, but all of them remain still undated (Rabassa et al., 2000). Nevertheless, the results obtained from pollen (Heusser, 1989a,b, 1998), dendrochronology (Villalba, 1989, 1994) and marine waters isotopic analyses (Obelic et al., 1998) compared with the Vostok ice-core (Jozuel et al., 1987) showed climatic reversal episodes in the region between 4400 and 3400, 2800–2000, 1800–1400 and 500 ^{14}C yr B.P. (Borromei et al., 2007). As pointed previously by Gordillo et al. (2005), most of these species, if not all of them, were able to persist in the area, even during Neoglacial climatic deterioration.

The study of a Holocene marine record in the Archipiélago Cormoranes (Río Ovando site) clearly shows the potential of organic-walled dinoflagellate cysts and mollusk assemblages associated with pollen studies to reconstruct paleoenvironmental conditions during the marine transgression into the Beagle Channel. Further palynological studies on additional records from other fossil marine sections in Tierra del Fuego will lead to a more comprehensive view of the Holocene paleoclimate development.

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