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First record of *Palaeostomocystis subtilitheca* in Holocene marine sediments from the Beagle Channel, southern Tierra del Fuego, Argentina

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ABSTRACT

This study documents the occurrence of *Palaeostomocystis subtilitheca* in Holocene sediments from the Beagle Channel area, southern Argentina, and represents the first record of this acritarch in high latitudes of the Southern Hemisphere. *P. subtilitheca* is considered as an indicator for polar to subpolar environments with high planktonic productivity and nutrient-rich waters and can probably be associated with low-salinity stratified waters. The Beagle Channel presents environmental characteristics similar to those reported by other authors in Central West Greenland and the Faroe Islands, characterized by high concentrations of nutrients in the surface waters. The Beagle Channel constitutes a favourable environment for the development of this species in subpolar regions of the Southern Hemisphere.

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1. Introduction

The term Acritarcha represents an informal category which comprises all the unicellular microfossils of polyphyletic origin and whose biological affinity is unknown. The group includes organic-walled vesicles with variable morphologies and/or ornamentations and excystment openings represented by a split, an irregular rupture, or a circular pylome (Martin, 1993). The acritarchs are commonly associated with marine environments and have been recorded from the Paleoproterozoic to Recent (Schrank, 2003; Huntley et al., 2006). However, Quaternary acritarchs are rare, although many of them are possibly associated with dinoflagellate cysts (dinocysts) or spores of algae (Mudie and Harland, 1996). Few contributions have documented the occurrence of acritarchs in Quaternary sediments along the Argentine coast and continental shelf (Grill and Guerstein, 1995; Grill and Quattrocchio, 1996; Gómez et al., 2005; Borel and Gómez, 2006; Borel, 2007, 2009). In Isla Grande de Tierra del Fuego, studies of marine organic-walled palynomorphs (dinocysts and acritarchs) were carried out in the area of the Beagle Channel by Borromei and Quattrocchio (2001, 2007), Grill et al. (2002), Candel (2010), Candel and Borromei (2013), Candel et al. (2009, 2011, 2012, 2013), and Rabassa et al. (2009).

The aim of this paper is to document the occurrence of *Palaeostomocystis subtilitheca* in modern and middle to late Holocene marine sediments from the Beagle Channel area, Tierra del Fuego. This study constitutes the first record of this species in high latitudes of the Southern Hemisphere and southern South America.

2. Study area

The Beagle Channel is an ancient tectonic valley that connects the extreme south of the Atlantic and Pacific oceans at latitude 54° 53′ S between longitude 66° 30′ and 70° W (Fig. 1). During the Last Glacial Maximum (ca. 25 ka BP, Rabassa et al., 2011), this valley was occupied by a large outlet glacier from the Darwin Cordillera, the Beagle Glacier. After ice-melt (ca. 8200 ^{14}C yr BP), the valley was occupied by lakes, peat bogs, and rivers. During the Holocene transgression around 7900 ^{14}C yr BP, the valley was submerged by the sea and the whole area turned into a fjord (Rabassa et al., 1986). The fjords are estuarine features caused by the marine flooding of ancient glacial valleys and are characterized by a salinity and/or temperature stratification of the water column. Furthermore, fjords are deep with steep slopes and generally rocky. One of the most remarkable morphological characteristics is the presence of one or more glacial "sills." These sills are defined as an elevation which can be a rocky remnant (threshold) or moraine deposits and the inner basin defined by them has the better known dynamic within the fjords (Syvitski and Shaw, 1995). The ideal model of a stratified fjord requires the presence of an outflowing freshwater layer and a compensating seawater layer entering into the estuary. This two-layer model ("fjord type") is typical of the summer or spring–autumn seasons; the fjord waters in winter are usually not stratified. The Beagle Channel presents an estuarine stratification;

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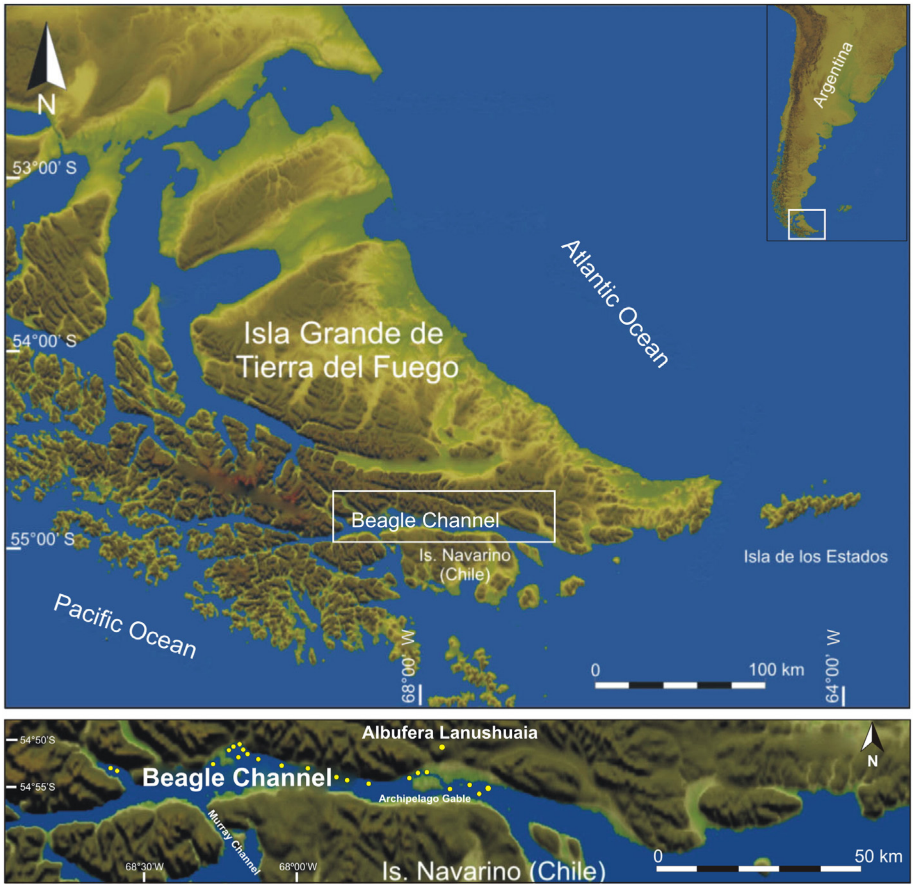


Fig. 1. Location map of the study area and sampling sites.

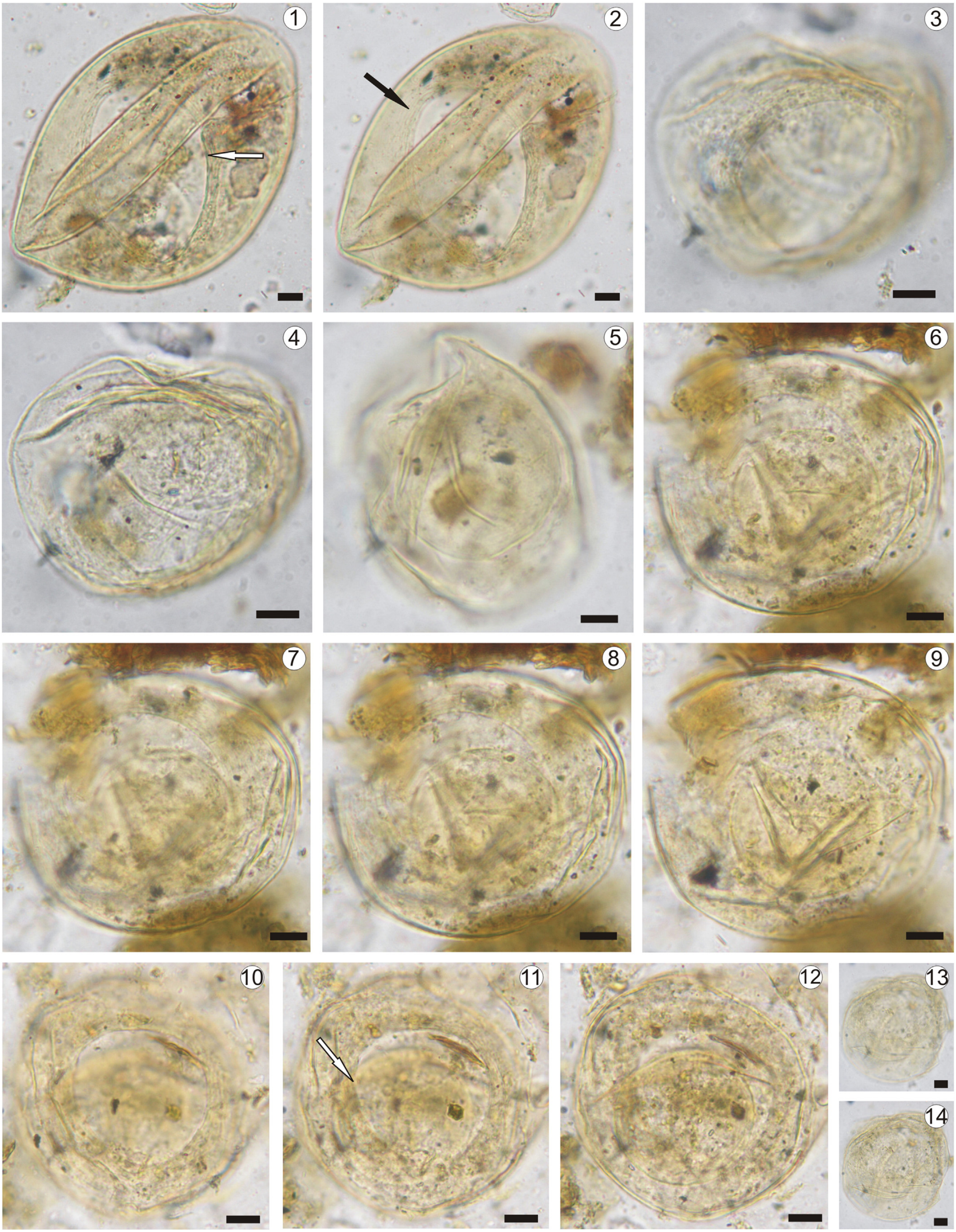
Table 1
Sampling site number, location, and sediment type of fossil and modern sediments from the Beagle Channel where *Palaeostomocystis subtilitheca* was recorded (modified from Candel et al., 2012).

		Locality name	Sample number	Laboratory number	Latitude	Longitude	Lithological description
Fossil profile		Albufera	AL91	1947	54°52′04.4″S	67°60′44.9″W	Clays with mollusc shells
		Lanushuaia (AL)	AL55	2584	54°52′04.4″S	67°60′44.9″W	Sandy-silt with mollusc shells
		(5800-5500 ^{14}C yr BP)	AL54	2585	54°52′04.4″S	67°60′44.9″W	Clays with vegetal remains and mollusc shells
Modern sediments	Central sector	Punta Remolino (PR)	FCB11	3167	54°51′23″S	68°03′21″W	Clay with mollusc shells
			FCB22	3862	54°51′37″S	67°56′02″W	Silt with mollusc shells
			FCB10	3166	54°52′16″S	67°51′36″W	Clay with mollusc shells
			FCB21	3172	54°52′11″S	67°49′13″W	Silty-clay with mollusc shells
		Punta Parana (PP)	FCB3	2347-3	54°52′45″S	67°45′30″W	Sandy-silt with mollusc shells
	Eastern sector	Isla Gable (IG)	FCB2	2347-2	54°52′15″S	67°33′00″W	Clay with mollusc shells
			FCB4b	3165	54°52′32″S	67°33′18″W	Clay with mollusc shells
			FCB1	2349-1	54°51′30″S	67°30′30″W	Silty-clay
		Exterior Isla Gable (EIG)	FCB16	3171	54°53′53″S	67°22′32″W	Clay with mollusc shells
			FCB14	3170	54°53′52″S	67°17′24″W	Silt with mollusc shells
			FCB12	3168	54°55′20″S	67°13′53″W	Fine grained to medium grained sand
			FCB13	3169	54°54′20″S	67°12′32″W	Clay

the waters of the channel 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 (Isla et al., 1999).

The narrowing (sill) of Archipelago Gable, Murray Channel, and the northwestern and southwestern Beagle Channel branches not only modify morphologically the fjord dynamics restricting water exchanges but also limit the relative effects of the eastern- and western-flowing tidal currents, and the gravity waves originating from the west

Plate I. *Palaeostomocystis subtilitheca* from surface sediments of the Beagle Channel, Tierra del Fuego. Scale bar: 10 μm. Sample number followed by England Finder coordinates. The black arrows indicate the concentric rings surrounding the pylome area. The white arrows indicate the deformation? of the pylome/operculum. 1–2, FCB3165: V25, 1: apical view, high focus; 2: apical view, low focus. 3–4, FCB3166: G27, 3: semilateral view, high focus; 4: semilateral view, low focus. 5, FCB3166: G25, apical view, low focus. 6–9, FCB3167: O17/2, 6: antapical view, low focus; 7: antapical view, mid focus; 8: antapical view, mid focus; 9: antapical view, high focus. 10–12, FCB3167: P47/1, 10: apical view, high focus; 11: apical view, mid focus; 12: apical view, low focus. 13–14, FCB3166: S17, 13: semilateral view, low focus; 14: semilateral view, high focus.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(D'Onofrio et al., 1989; Isla et al., 1999). The annual 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 recorded 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 freshwater sources, and by tidal flow from both the east (Atlantic) and the west (Pacific) (Isla et al., 1999).

3. Material and methods

The study was carried out on twenty-seven samples from a sediment core located in Albufera Lanushuaia (54° 52′ 04.4″ S–67° 60′ 44.9″ W; north coast of Beagle Channel) and twenty-two surface samples collected from the bottom of the Beagle Channel, between Bahía Lapataia and Punta Navarro, Tierra del Fuego (Fig. 1). Specimens of *Palaeostomocystis subtilitheca* were previously described as Acritarch sp. 1 in marine sediments from the Beagle Channel (Candel, 2010; Candel et al., 2011, 2012, 2013; Candel and Borromei, 2013). These acritarchs were restudied and are here assigned to *P. subtilitheca.* The species described and illustrated in this paper were recorded in the mid-lower part of the fossil section at 55–91 cm, dated between 5800 and 5500 ^{14}C yr BP. (Table 1). The species was recorded in modern sediment samples from the central and eastern sectors of the Beagle Channel. The lithology consists of dark grey clays and dark brown medium-coarse sands with abundant shells (Table 1).

The fossil samples were processed for palynological analysis according to Heusser and Stock's techniques (1984), to concentrate the palynomorphs by use of HCl and HF acid treatments, dispersants ($Na_4P_2O_7$, KOH), and nylon sieves (150 and 10 μm mesh screens). Following the procedure advocated by Dale (1976), no oxidation and no acetolysis was applied in order to prevent the loss of more fragile palynomorphs, especially microplankton. The surface samples were prepared according to the laboratory procedures suggested by de Vernal et al. (1999). Samples were sieved through 150 and 10 μm mesh screens in order to remove coarse sand, silt, and clay particles. The sediment fraction between 150 and 10 μm was treated repetitively with hydrochloric and hydrofluoric acids to remove carbonates and silicates, respectively. The residue was sieved through a 10 μm mesh screen to concentrate the palynomorphs and mounted on microscopy slides with glycerine jelly. The material was studied with a transmitted light microscope at 1000× magnification. The specimens of *Palaeostomocystis subtilitheca* are shown in Plates I and II. 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: Al (Albufera Lanushuaia) and FCB (Fondo Canal Beagle). The taxonomy follows Fensome et al. (2008).

4. Systematic palynology

Group **ACRITARCHA** Evitt, 1963
Genus *Palaeostomocystis* Deflandre 1937
Palaeostomocystis subtilitheca Roncaglia, 2004

Description: Organic-walled, single-layered vesicle with a sub-circular to -ovoidal outline in polar view. The wall surface is smooth to slightly granular and colorless to brown pale in color. The vesicle is spherical to subspherical in lateral view. It presents a large circular pylome characterized by concentric rings surrounding the opening area. A circular operculum detached, psilate to microgranulate, usually is observed in the interior of the vesicle.
Dimensions: Vesicle diameter: 62.4–(81.2)–136 μm. Pylome diameter: 29.6–(42.4)–73.5 μm, 20 specimens measured.
Studied material: UNSP FCB3165: V25; UNSP FCB3166: U29/2, S17, P12, G25, H27/3; UNSP FCB3167: O41/2, L51/3, M19/2, M20/1, P47/1, K29/2, E32, C34, T4, O17/2; UNSP FCB3169: J34/2; UNSP AL2584: V53/3, L56/1, T30/4.
Remarks: Specimens of *Palaeostomocystis subtilitheca* recovered from the Beagle Channel sediments show morphological characteristics similar with those specimens from the Northern Hemisphere described by Roncaglia (2004a), especially the general shape of the vesicle, the wall surface, and the macropylome. However, some specimens observed in this study have a larger size of the vesicle than those previously documented for this species (vesicle length: 45–55 μm, width vesicle: 52.8–78 μm; Roncaglia, 2004a). In some cases, the pylome and/or operculum show a sub-circular to sub-ovoidal outline probably due to deformation (Plate I, 1, 11; Plate II, 7). Also, the solid blunt horn and the small pseudopylome in the antapical region described for the holotype were not distinguished in the specimens studied in this work due to the orientation and/or poor preservation.

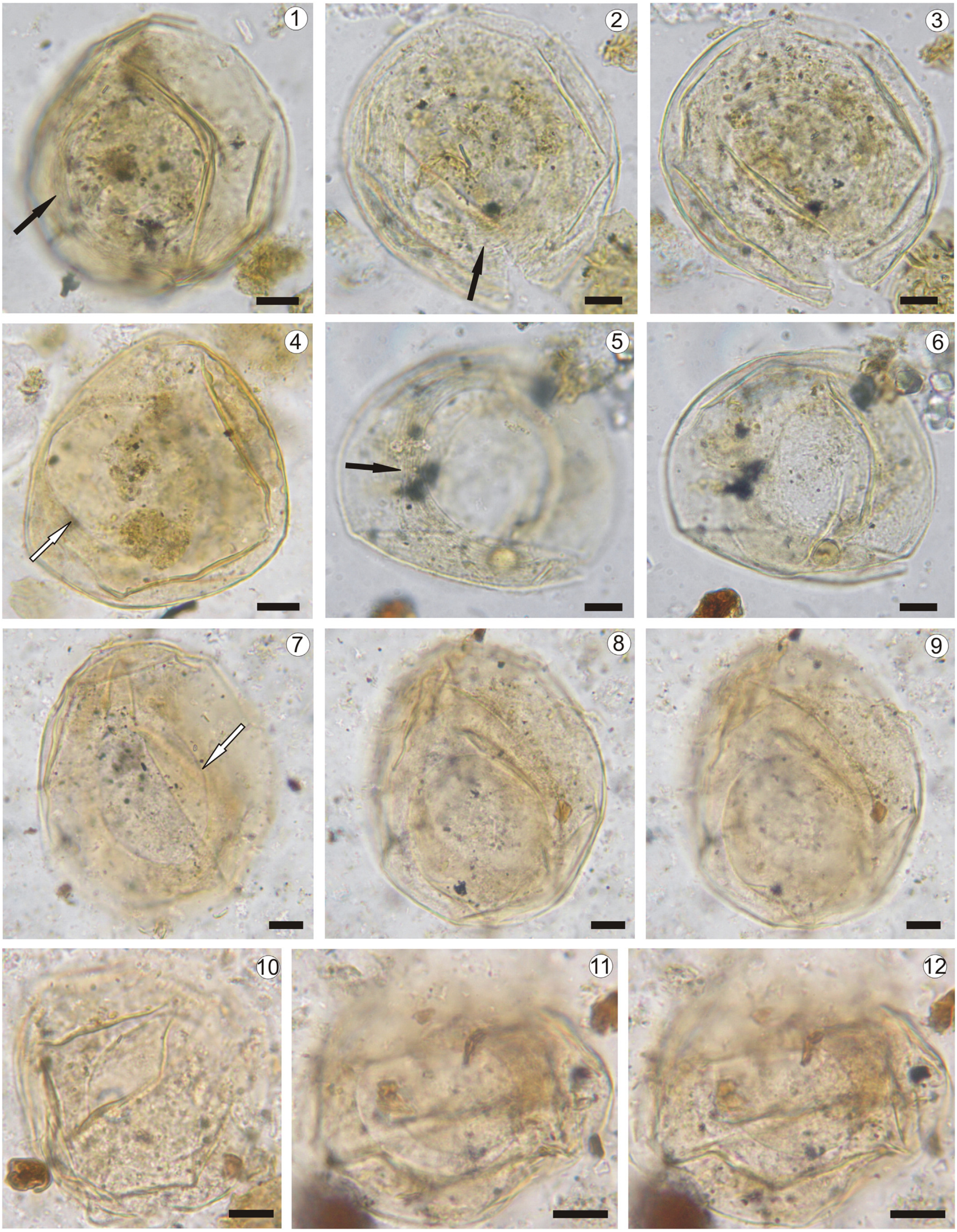
The Acritarch sp. 1 identified in marine sediments from the Beagle Channel (Candel, 2010; Candel et al., 2011, 2012, 2013; Candel and Borromei, 2013) has been restudied and is assigned to *Palaeostomocystis subtilitheca.*

5. Discussion

Palaeostomocystis subtilitheca species shows a great morphological variability which could lead to similarities with other species of *Palaeostomocystis* or other genera; however, the characteristic features of this species such as the circular to ovoidal outline of the vesicle, wall type, and large pylome in relation to the overall size of the vesicle, allows its identification and assignment into *P. subtilitheca.* According to Roncaglia (2004a, 2004b), *Palaeostomocystis subtilitheca* differs from other species such as *P. pachytheca* (Cookson and Eisenack, 1971; Jansonius, 1989), *P. ovata* (Wilson, 1967; Eisenack et al., 1973), and *P. fritilla* (Bujak, 1984; Roncaglia, 2004a, 2004b), by having a very thin, transparent wall and larger vesicle size (62.4–136 μm). It also differs from these species by exhibiting a smooth to microgranulate wall and a detached operculum. *Palaeostomocystis subtilitheca* bears similarities to *P. orbiculata* (Verhoeven et al., 2014) in a general view, but differs by having a larger vesicle size (*P. subtilitheca*: 62.4–136 μm; this study) and the absence of an irregular net-like ornamentation. Furthermore, *Palaeostomocystis subtilitheca* exhibits similarity to *Leiosphaeridia* (Eisenack, 1958; Downie and Sarjeant, 1963), by its thin wall and the lack of wall surface ornamentation, although the ovoidal to obtusiconiform with circular to ovoidal equatorial outline and the large size of the pylome in *P. subtilitheca* (29.6 − (42.4) − 73.5 μm; this study) allow differentiating clearly this species.

Regarding its ecological preferences, *Palaeostomocystis subtilitheca* was documented by Roncaglia (2004a, b) in Holocene sediments from

Plate II. *Palaeostomocystis subtilitheca* from modern and fossil marine sediments from the north coast of the Beagle Channel, Tierra del Fuego. Scale bar: 10 μm. Sample number followed by England Finder coordinates. The black arrows indicate the concentric rings surrounding the pylome area. The white arrows indicate the deformation? of the pylome/operculum. 1, FCB3167: T4, apical view, high focus. 2–3, FCB3167: O41/2, 2: apical view, high focus; 3. apical view, low focus. 4, FCB3167: K29/2, semilateral view, high focus. 5–6, FCB3169: J34/2, 5: apical view, high focus; 6: apical view, mid focus. 7–9, AL2584: T30/4 (Candel, 2010, Plate 10.4; Candel et al., 2011, Plate 4.K), 7: apical view, high focus; 8: apical view, mid focus; 9: apical view, low focus. 10, AL2584: V53/3, antapical view, high focus. 11–12, AL2584: L56/1 (Candel, 2010, Plate 10.3; Candel et al., 2011, Plate 4.J; Candel and Borromei, 2013, Plate 3.7), 11: apical view, high focus; 12: apical view, low focus.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the central-western Greenland and the Faroe Islands, in the high latitudes of the Northern Hemisphere. The highest abundance was recorded in sediments deposited under stratified waters conditions mainly during the summer months, with a seawater surface temperature of 4 °C and salinities ≤ 33.25. Based on these data, Roncaglia (2004a) inferred that *Palaeostomocystis subtilitheca* is an indicator of subpolar to polar conditions. This species also has been recorded in glaciomarine sediments from marine channels with high river discharge and important winter ice-cover in the Canadian Arctic Archipelago, Northern Hemisphere by Pieńkowski et al. (2011, 2013).

In the Southern Hemisphere, Warny (2009) reported, with exception of *P. subtilitheca*, other species of *Palaeostomocystis* in glaciomarine sediments of late Pleistocene located on the Antarctic Peninsula. The highest abundances of this genus were found in neritic environments with nutrient-rich waters and subpolar to polar conditions, consistent with those reported by other authors in the Bering Sea (Bujak, 1984), Greenland (Roncaglia, 2004a, b; Ribeiro et al., 2012), and other subpolar areas from the Northern Hemisphere (Pieńkowski et al., 2011, 2013).

Palaeostomocystis subtilitheca is recorded here in marine sediments from the Beagle Channel, Tierra del Fuego, Southern Argentina. The Beagle Channel presents environmental characteristics similar to those reported by Roncaglia (2004a, b) in Egedesminde Dyb and Kangersuneq Fjord, Disko Bugt, central West Greenland, and from Skálafjord, Eysturoy, Faroe Islands. Pieńkowski et al. (2011, 2013) reported similar conditions in Coronation Gulf and Parry Channel, Canadian Arctic Archipelago.

The Beagle Channel waters are influenced by strong freshwater discharge from rainfall and glaciers through the rivers draining the intermontane basins associated with cirque glaciers (Isla et al., 1999). The water column is stratified mainly during the summer season, with an annual average sea-surface temperature about 6.5 °C and sea-surface salinity varies from 27 to 33.5 with minimum values during summer due to the meltwater discharge into the channel (Isla et al., 1999).

Palaeostomocystis subtilitheca was recorded as Acritarch sp. 1 in middle-late Holocene sediments (5800–5500 ^{14}C yr BP) from Albufera Lanushuaia together with terrestrial and other aquatic palynomorphs such as *Halodinium* sp., Zygnemataceae and Prasinophyceae algae, copepod eggs, and foraminiferal linings. This assemblage suggests a marginal marine environment with high nutrient levels, probably caused by freshwater runoff (Candel et al., 2011; Candel and Borromei, 2013). Also, *P. subtilitheca* was recorded in high numbers in Holocene marine sediments from Aserradero-Lapataia 2 and Arroyo Baliza sites, located in the western sector of the Beagle Channel. This species is accompanied mainly by peridinioid dinocysts, acritarchs, and freshwater to brackish-marine algae (M.S.C., pers. obs.).

In the modern sediments from the Beagle Channel, *P. subtilitheca* was recorded mainly in the central and eastern sectors of the channel. Today, the central sector has a moderate number of fluvial streams coming from smaller interior basins than those of the western part of the Beagle Channel. In these samples, *Palaeostomocystis subtilitheca* is mainly associated with peridinioid dinocysts (such as *Brigantedinium* spp., *Selenopemphix quanta*, *Echinidinium* spp., *Islandinium minutum*, and *Votadinium spinosum*, among others), together with other aquatic palynomorphs such as foraminiferal linings, copepod eggs, and acritarchs, suggesting the proximity of a terrestrial source of high input of organic matter in the marginal-marine environment under restricted circulation conditions (Candel et al., 2012). In the eastern sector of the channel, *P. subtilitheca* was recorded in assemblages composed mainly of foraminiferal linings, together with dinocysts such as *Brigantedinium* spp., cyst of *Pentapharsodinium dalei*, *Spiniferites* spp. and *Islandinium minutum*, Among others. Other aquatic palynomorphs included copepod eggs, *Halodinium* sp., freshwater and brackish-marine algae such as *Botryococcus* sp., Zygnemataceae, *Radiosperma corbiferum*, and *Polyasterias* sp. It suggests a transitional-marine environment with nutrient-rich waters and variable salinities due to freshwater input by rivers.

In summary, the records of *Palaeostomocystis subtilitheca* in sediments from Beagle Channel are associated with nutrient-rich, cold, and low-salinity stratified waters and, therefore, are consistent with the previously documented records of *P. subtilitheca* in subpolar areas from the Northern Hemisphere.

6. Conclusions

The species *Palaeostomocystis subtilitheca* described in this paper represents a new finding in high latitudes of the Southern Hemisphere. Despite the fact that other species of the genus *Palaeostomocystis* were documented for Antarctic regions (Warny, 2009), the species *P. subtilitheca* has not been documented before in subpolar areas of the Southern Hemisphere and, its occurrence in modern and Mid-Late Holocene marine sediments from the Beagle Channel area represents its first record for southern South America.

Palaeostomocystis subtilitheca is considered as an indicator of polar to subpolar environments with low surface salinity, high planktonic productivity, and nutrient-rich waters. The Beagle Channel, characterized by cold waters and high concentrations of nutrients caused by freshwater input from glacier meltwater, constitutes an appropriate environment for its development in the southernmost part of South America.

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