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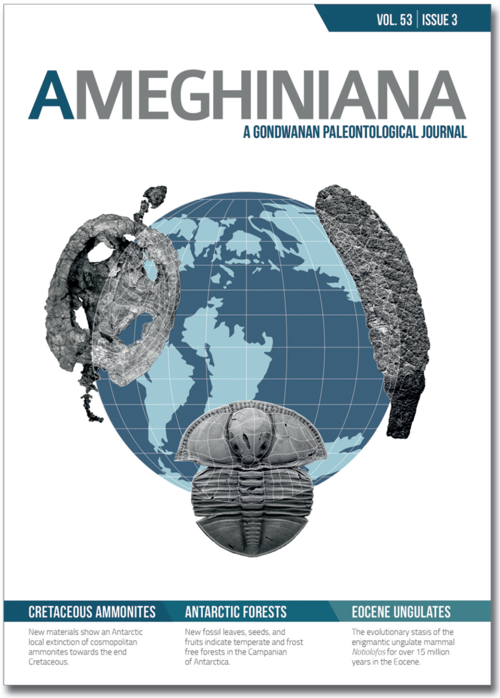

UPPER CRETACEOUS FORAMINIFERA AND PALYNOMORPHS FROM EKELÖF COAST SECTION, EKELÖF POINT, EASTERN JAMES ROSS ISLAND, ANTARCTIC PENINSULA

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GONDWANAN PERSPECTIVES

UPPER CRETACEOUS FORAMINIFERA AND PALYNOMORPHS FROM EKELÖF COAST SECTION, EKELÖF POINT, EASTERN JAMES ROSS ISLAND, ANTARCTIC PENINSULA

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Abstract. A micropaleontological analysis of foraminifera and palynomorphs obtained from a partial sedimentary section cropping out at Ekelöf Point, eastern James Ross Island, Antarctic Peninsula, is presented. The section, named Ekelöf Coast, includes the lowest levels of the Upper Cretaceous Hamilton Point Member of the Snow Hill Island Formation. Among the foraminifera, 18 benthic taxa including 10 agglutinated and eight calcareous are recognized. Palynomorphs include continental and marine species. The continental assemblage contains 44 spore and pollen species. The marine assemblage consists of 10 peridinioid dinoflagellate cysts species, dominating in number of specimens, and 10 gonyaulacoids. Although the palynomorph assemblage supports a late Campanian age for the section, an earliest Maastrichtian age is not excluded. The paleoenvironmental interpretation based on the distribution of foraminiferal morphogroups indicates an outer shelf-upper bathyal environment in agreement with sedimentological data. The paleoenvironmental inference based on the S/D ratio (sporomorph *versus* dinoflagellate cysts) and the P/G ratio (peridinioid *versus* gonyaulacoid cysts) suggest a coastal to inner neritic setting with a continuous continental supply from the continent to the marine environment, evidenced by the slight dominance of the peridionoids over gonyaulacoids cysts. The discrepancy observed between palynological and micropaleontological-sedimentological data may be linked to the development of a narrow continental shelf during the Late Cretaceous. In such continental shelf, terrestrial palynomorphs and peridinoid cysts would quickly run down the slope and would be deposited in the deep marine environment together with gonyaulacoid cysts.

Key words. Foraminifera. Palynomorphs. Upper Cretaceous. James Ross Island. Antarctic Peninsula.

Resumen. FORAMINÍFEROS Y PALINOMORFOS DEL CRETÁCICO SUPERIOR DE LA SECCIÓN EKELÖF COSTA, PUNTA EKELÖF, ESTE DE LA ISLA JAMES ROSS, PENÍNSULA ANTÁRTICA. Se presenta un análisis micropaleontológico de los foraminíferos y palinomorfos obtenidos de una sucesión sedimentaria parcial que aflora en Punta Ekelöf, este de la Isla James Ross, Península Antártica. La sección denominada Ekelöf Costa, incluye los niveles inferiores de las sedimentitas del Cretácico Superior correspondientes al Miembro Hamilton de la Formación Snow Hill Island. Entre los foraminíferos se reconocen 18 taxones bentónicos, 10 aglutinados y ocho calcáreos. Los palinomorfos incluyen especies marinas y continentales. La asociación continental contiene 44 especies de esporas y polen. La asociación marina consta de 10 especies de quistes de dinoflagelados peridinoides y 10 especies de gonyaulacoides, siendo los peridinoides dominantes en cuanto al número de ejemplares. La asociación palinológica indica una edad campaniana tardía, pero no se excluye una edad maastrichtiana más temprana para la sección analizada. La interpretación paleoambiental realizada sobre la base de la distribución de los morfogrupos de foraminíferos sugiere una plataforma externa a batial superior, que coincide con datos sedimentológicos. Las inferencias paleoambientales basadas en la relación S/D (esporomorfos *versus* quistes de dinoflagelados) y P/G (peridinoides *versus* gonyaulacoides) sugieren un ambiente costero a nerítico interno con un aporte continental contínuo desde el continente hacia el ambiente marino, evidenciado por el predominio de los quistes de peridinoides sobre los quistes de gonyaulacoides. La discrepancia entre la interpretación paleoambiental que surge de los datos palinológicos y los micropalentológicos-sedimentológicos podría estar relacionada con el desarrollo de una plataforma continental estrecha durante el Cretácico Tardío, donde los palinomorfos continentales y los quistes de dinoflagelados peridinoides rápidamente se habrían deslizado por la plataforma depositándose en el ambiente marino profundo junto a los quistes gonyaulacoides.

Palabras clave. Foraminíferos. Palinomorfos. Cretácico Superior. Isla James Ross. Península Antártica.

FORAMINIFERAL and palynological information from the Upper Cretaceous of eastern James Ross Island is scarce, particularly at Ekelöf Point, where a poorly known thick Cretaceous marine sedimentary succession crops out. Up to now, micropaleontological studies in this locality are restricted to a small amount of contributions regarding foraminifera. This input derives from research carried out in some partial sections of Ekelöf Point such as Chorrillo Leonardo and Ekelöf

Ovest, identified by Gennari (1997), which exhibit slightly higher stratigraphic levels than the section treated herein. These studies, of which none are accompanied by illustrations of foraminifera, include an unpublished taxonomic analysis (Gennari, 1997) and some paleoecological inferences presented by Concheyro *et al.* (1997) and Morlotti and Concheyro (1999). Previous palynological studies of the Upper Cretaceous sediments cropping out at Ekelöf Point are those of Sumner (1992) and Pirrie *et al.* (1997a). Sumner (1992) analyzed the marine assemblage of 17 samples collected from 34.5 m of sedimentary rocks exposed along the coastline of the Ekelöf Point locality and probably corresponding to the same levels of the Ekelöf Coast section herein examined. Based on the dinoflagellate cysts, he discussed the age of the section and proposed a nearshore setting. In spite of the significant number of studied samples, he noticed that his paleoenvironmental approach did not fit with the sedimentological and regional data. According to the author, there is no evidence supporting wave generated structures in the exposure and this would indicate water depths of more than 150 m. Later, Pirrie *et al.* (1997a) presented a stratigraphic and sedimentological study of the Marambio Group in southeastern James Ross Island. Although this contribution included preliminary paleontological results based on ammonites and palynomorphs, only three palynological samples from Ekelöf Point were analyzed and poorly illustrated. The objectives of this study are to introduce and illustrate the Upper Cretaceous foraminiferal assemblages of one partial section at Ekelöf Point as well as documenting the associated palynomorphs recovered from the same samples. Additionally, we discuss the paleoenvironmental settings based on analyzing the foraminifera and palynomorphs assemblages.

GEOLOGICAL SETTING

The James Ross Basin is a backarc sedimentary basin located in the northeastern tip of the Antarctic Peninsula. It constitutes a remarkable basin more than 6,000 m thick of extensive and well-exposed Mesozoic and Paleogene sedimentary rocks cropping out.

The outcrops of this basin are scattered over the eastern sector of the Antarctic Peninsula as well as around the James Ross, Vega, Humps, Cockburn, Seymour (= Marambio), Snow Hill and Lockyer islands (Bibby, 1966; Rinaldi, 1982; Olivero *et al.*, 1986; Marenssi *et al.*, 2001; Olivero, 2012a). In James Ross Island, Cretaceous sediments are restricted to the north, west, east and southeast areas (Fig. 1). Upper Cretaceous sedimentary successions are particularly well exposed in the east and southeast areas of this island, that is, Ekelöf Point, Rabot Point, Hamilton Norte (= Redshaw Point) and Hamilton Point (Lirio *et al.*, 1989; Pirrie *et al.*, 1997a).

At Ekelöf Point (64° 13′ 26.0″ S; 57° 12′ 14.0″ W), Upper Cretaceous sedimentary rocks were assigned to the Hamilton Point Member of the Santa Marta Formation by Pirrie *et al.* (1997a). Later, Olivero (2012a, fig. 1) incorporated the Hamilton Point Member to the Snow Hill Island Formation. This unit is overlain by Cenozoic diamictites of the Hobbs Glacier Formation (Pirrie *et al.*, 1997b; Nelson *et al.,* 2009)

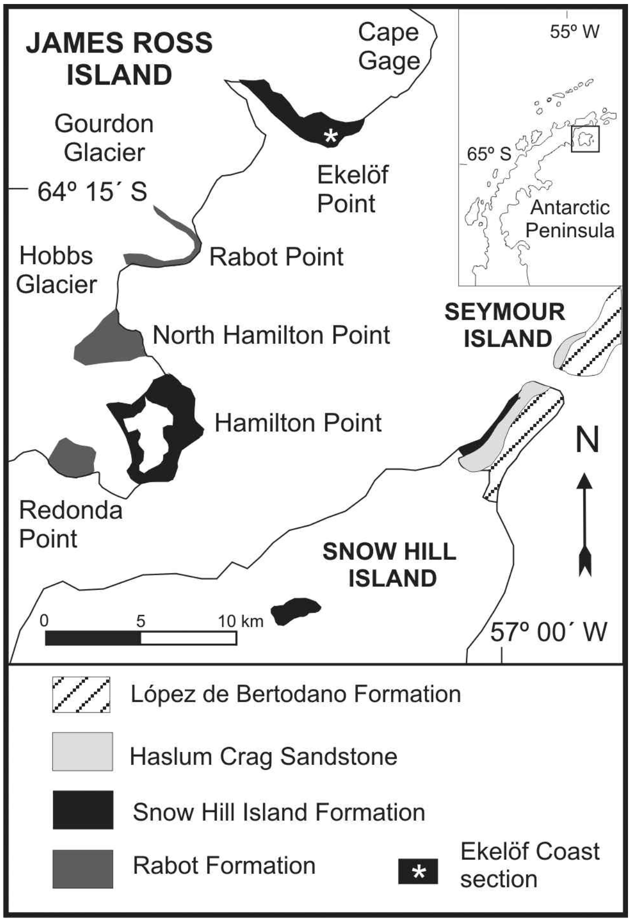


Figure 1. Location map of the Ekelöf Coast section relative to the Antarctic Peninsula showing the Cretaceous outcrops in eastern and southeastern James Ross Island, northeastern Snow Hill Island and southern Seymour Island (modified from Strelin and Malagnino, 1992; Olivero *et al.*, 2008; Olivero, 2012b).

and basalts and volcaniclastic rocks of the Neogene James Ross Island Volcanic Group (Nelson, 1975; Smellie *et al.*, 2008).

At Ekelöf Point, the Snow Hill Island Formation is 325 m thick and consists of slightly laminated to massive clayed siltstones, vitric and vitric-crystalline tuffs. These monotonous sedimentary rocks, which originated by decantation of suspended fine-grained particles with occasional ash falls derived from a volcanic arc, represent a quiet environment below storm wave-base between the outer shelf and slope (Robles Hurtado *et al.*, 1997). Recent fieldwork allowed us to sample in detail a partial section of these sediments exposed along the coastline in which a conspicuous concretionary level with abundant trace fossils interbedded with clayed siltstones, claystones and tuffs appeared (Fig. 2).

MATERIALS AND METHODS

The studied material comprises six samples (EC-1, EC-5, EC-9, EC-13, EC-15 and EC-19) collected from the Ekelöf Coast section exposed along the coastline of Ekelöf Point (Fig. 2). The studied stratigraphic section (*ca.* 45 m thick) consists of dark gray siltstones and claystones alternating with thin indurated tuff beds and yellow claystones as well as a concretionary horizon containing trace fossils near the middle part of the section (Fig. 2). Although the samples yielded both foraminifera and palynomorphs, they were barren of calcareous nannofossils.

For foraminiferal studies, approximately 100 g of sediment were disaggregated in hydrogen peroxide solution (5%, 200 vols.) and washed over 74 μm and 297 μm sieves. The washed samples were dried and all foraminiferal specimens were picked. Foraminifers recovered from the Ekelöf Coast section are described in the Systematic Paleontology section and the distribution of the species is illustrated in Table 1. Specimens figured herein (Figs. 3 and 4) are housed in the micropaleontological collections of the Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires (Buenos Aires, Argentina), under the prefix **LM-FCEN** with the assigned catalogue numbers 3726–3751.

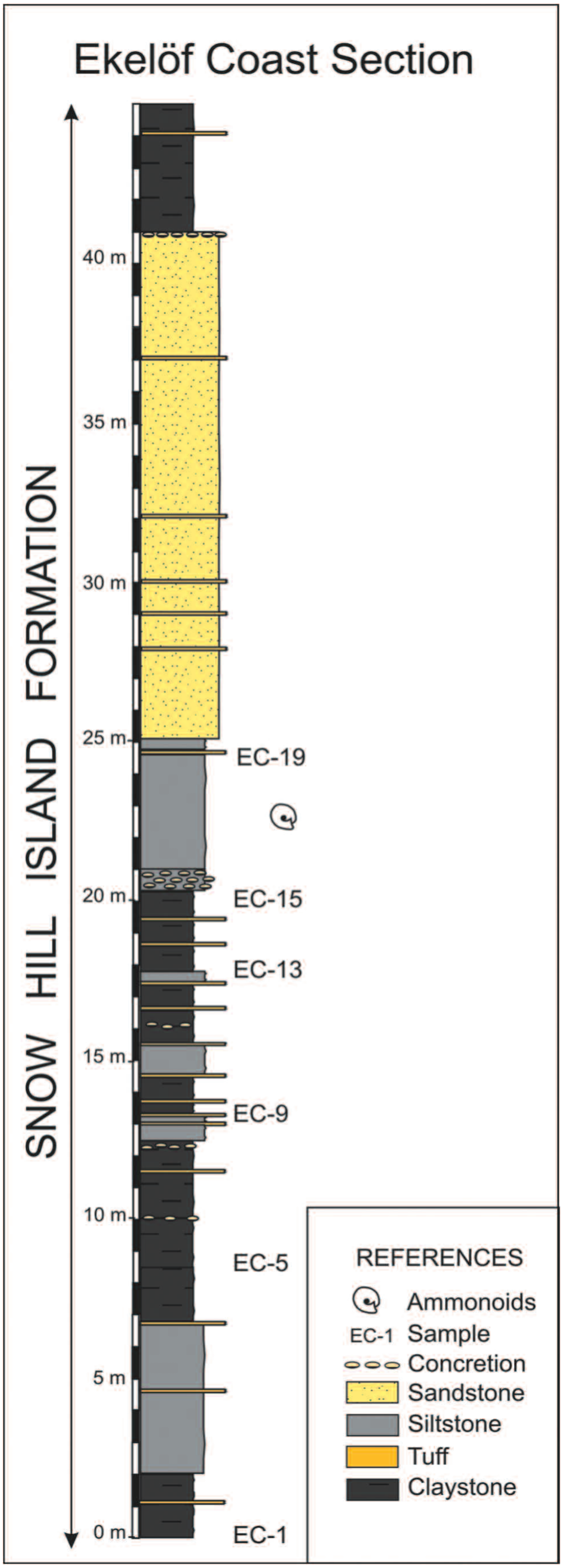


Figure 2. Stratigraphic log of the Ekelöf Coast section, eastern James Ross Island, Antarctic Peninsula.

Due to the scarcity of benthic foraminifer specimens and the absence of planktonic foraminifers, quantitative analyses for paleoecological interpretation of fossil assemblages were not performed. Instead, the distribution of foraminiferal morphogroups was used as an indicator of particular paleoenvironmental conditions (Koutsoukos and Hart, 1990; Nagy *et al*., 1995; van der Akker *et al.,* 2000; Kaminski and Gradstein, 2005; Cetean *et al.,* 2011).

Micropaleontological samples for calcareous nannofossils were processed following standard procedures (Bown and Young, 1998) but none of them yielded nannoflora.

Palynomorphs were extracted from samples according to standard procedures of removing organic matter by digesting the carbonates and silicates with HCl and HF, respectively (Wood *et al*., 1996). The residue was sieved with a 10 µm mesh and finally mounted on microscope slides with glycerine gel.

The recovered palynomorphs are listed in Table 2. Selected specimens are illustrated in Figure 5 and each is marked by the prefix **BAFC-Pl** corresponding to the Palynological Collection of the Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires (Buenos Aires, Argentina), followed by the slide number and the England Finder coordinates.

It was possible to count a minimum of 200 palynomorphs including dinoflagellate cysts, pollen, spores and other palynomorphs (algae, organic foraminiferal linings, scolecodonts, fungi, etc.) in all samples. For paleoenvironmental analyses, the following indexes were considered: the S/D ratio, sporomorph *versus* dinoflagellate cyst (Versteegh, 1994) and the P/G ratio, peridinioid *versus* gonyaulacoid cysts (Harland, 1973).

SYSTEMATIC PALEONTOLOGY OF FORAMINIFERA

The suprageneric taxonomy used herein follows the World Foraminifera Database (Hayward *et al*., 2015) and the generic taxonomic classification is based on Loeblich and Tappan (1987). Open nomenclature has been used for taxa that do not closely correspond to published descriptions; cf. for taxa similar to a known species but with few or poorly preserved specimens. In order to clarify the identification of

TABLE 1 – Occurrences of foraminiferal species from the Ekelöf Coast section.

LITHOSTRATIGRAPHY	*SAMPLES*	**Bathysiphon** *spp.*	**Reticulophragmoides jarvisi**	**Rzehakina minima**	**Gavelinella sandidgei**	**Prodentalina** *? sp.*	**Ammobaculites wazaczi**	**Laevidentalina megalopolitana**	**Hemirobulina** *sp. cf.* **H. curvatura**	**Ammodiscus glabratus**	**Lingulonodosaria** *sp.*	*fragmented nodosarid*	**Buliminella isabelleana** *Camacho form* **procera**	**Lagena** *sp. cf.* **L. apiculata**	**Spiroplectammina chicoana**	**Reophax globosus**	**Recurvoides** *sp.*	**Ammodiscus** *? spp.*	**Ammodiscus peruvianus**	*specimens*	*species*	*% agglutinated specimens*	*% calcareous specimens*	*% epifaunal specimens*	*% surficial epifauna and shallow infauna specimens*	*% deep infauna specimens*
SNOW HILL ISLAND Fm.	*EC-19*	*13*	*3*												*5*	*13*	*1*			*35*	*5*	*100*	*0*	*37.1*	*25.7*	*37.2*
	EC-15	*38*	*5*				*6*			*3*					*47*	*15*	*5*	*4*	*1*	*124*	*9*	*100*	*0*	*30.6*	*52.4*	*17*
	EC-13	*23*	*2*	*3*	*1*										*1*					*30*	*5*	*99.7*	*0.3*	*80*	*20*	*0*
	EC-9	*18*	*7*	*1*	*4*								*1*	*1*						*32*	*6*	*81.2*	*18.8*	*68.7*	*31.3*	*0*
	EC-5				*5*							*1*								*6*	*2*	*0*	*100*	*83.3*	*16.7*	*0*
	EC-1	*13*	*7*	*5*	*4*	*1*	*1*	*1*	*1*	*1*	*1*									*35*	*10*	*77.1*	*22.9*	*48.6*	*48.6*	*2.8*

the species, the original description and some substantive references, especially regarding Antarctica and southern Argentina, are included. Species occurrences and their distribution are illustrated in a range chart (Tab. 1).

The six studied samples that yielded foraminifers exhibit poor to moderate preservation. A total of 18 benthic foraminiferal taxa, of which 10 are agglutinated and eight are calcareous, were recognized. No planktonic species were recovered from any sample.

Phylum Foraminifera
Class Foraminifera incertae sedis
Order Lagenida
Superfamily Nodosarioidea
Family Lagenidae Reuss, 1862

Genus ***Lagena*** Walker and Boys, 1784

Type species. *Serpula* (*Lagena*) *sulcata* Walker and Jacob, in Kanmacher, 1798.

Lagena sp. cf. ***Lagena apiculata*** (Reuss, 1851)
Figure 3.1

1851. *Oolina apiculata* Reuss, p. 22, pl. 2, fig. 1.

Description. Test unilocular, globose, oval in side view, circular in transverse section, greatest width close to the middle part of the test, apex pointed; wall calcareous, finely perforate; aperture is a small round opening at the end of a short neck.

Remarks. The specimen is similar to *O. apiculata*, described from the Upper Cretaceous of Poland, but differs from the original illustration of this species in presenting a smaller test with an oval outline instead of a pyriform one.

Family Nodosariidae Ehrenberg, 1838
Subfamily Lingulininae Loeblich and Tappan, 1961

Genus ***Lingulonodosaria*** Silvestri, 1903

Type species. *Lingulina nodosaria* Reuss, 1863.

Lingulonodosaria sp.
Figure 3.2

Description. Test fragmented, elongate, uniserial, compressed, transverse section ovate, with three inflated chambers, gradually increasing in width; sutures straight and horizontal, strongly depressed; wall smooth, finely perforated; foramen terminal.

Subfamily Nodosariinae Ehrenberg, 1838

Genus ***Laevidentalina*** Loeblich and Tappan, 1986

Type species. *Laevidentalina aphelis* Loeblich and Tappan, 1986.

Laevidentalina megalopolitana (Reuss, 1855)
Figure 3.3

1855. *Dentalina megalopolitana* Reuss, p. 267, pl. 8. fig. 10.
1988. *Dentalina megapolitana* Reuss. Huber, p. 196, fig. 19.19.

Description. Test uniserial, elongate, circular in section, consisting of seven chambers, not inflated, gradually increasing in width; sutures not depressed, straight and horizontal; wall smooth, finely perforate; foramen circular, terminal and slightly excentric.

Remarks. This species was originally described from the Turonian of Germany and is reported as a cosmopolitan species with Upper Cretaceous distribution. It was also recovered from the López de Bertodano Formation on Seymour and Vega Islands by Huber (1988) in stratigraphic intervals assigned to the early–late Maastrichtian (Olivero, 2012a,b).

Family Vaginulinidae Reuss, 1860
Subfamily Marginulininae Wedekind, 1937

Genus ***Hemirobulina*** Stache, 1864

Type species. *Cristellaria* (*Hemirobulina*) *arcuatula* Stache, 1864.

Hemirobulina sp. cf. ***Hemirobulina curvatura***
(Cushman, 1938)
Figure 3.4

cf. 1938. *Marginulina curvatura* Cushman, p. 34, pl. 5, figs. 13–14.
1988. *Marginulina* cf. *M. curvatura* Cushman. Huber, p. 197, fig. 21.9–10.

Description. Test globose, initially slightly coiled, with five chambers rapidly increasing in size, the last uncoiled, circular in transverse section; sutures depressed, gently curved; wall finely perforate, exhibiting an irregular rough surface under binocular microscope probably resulting from dissolution processes; aperture terminal, eccentrical, radiate, produced on a neck.

Remarks. Both the specimen from the Ekelöf Coast section and the material illustrated by Huber (1988) from the López de Bertodano Formation on Seymour Island in stratigraphic intervals assigned to the early–late Maastrichtian (Olivero, 2012a,b), seem to be more robust and compact than the original illustration of the species from the Upper Cretaceous Navarro Group, Texas (United States). Furthermore, our specimen differs from the specimens illustrated by Huber (1988) in presenting more inflated chambers and a more developed neck.

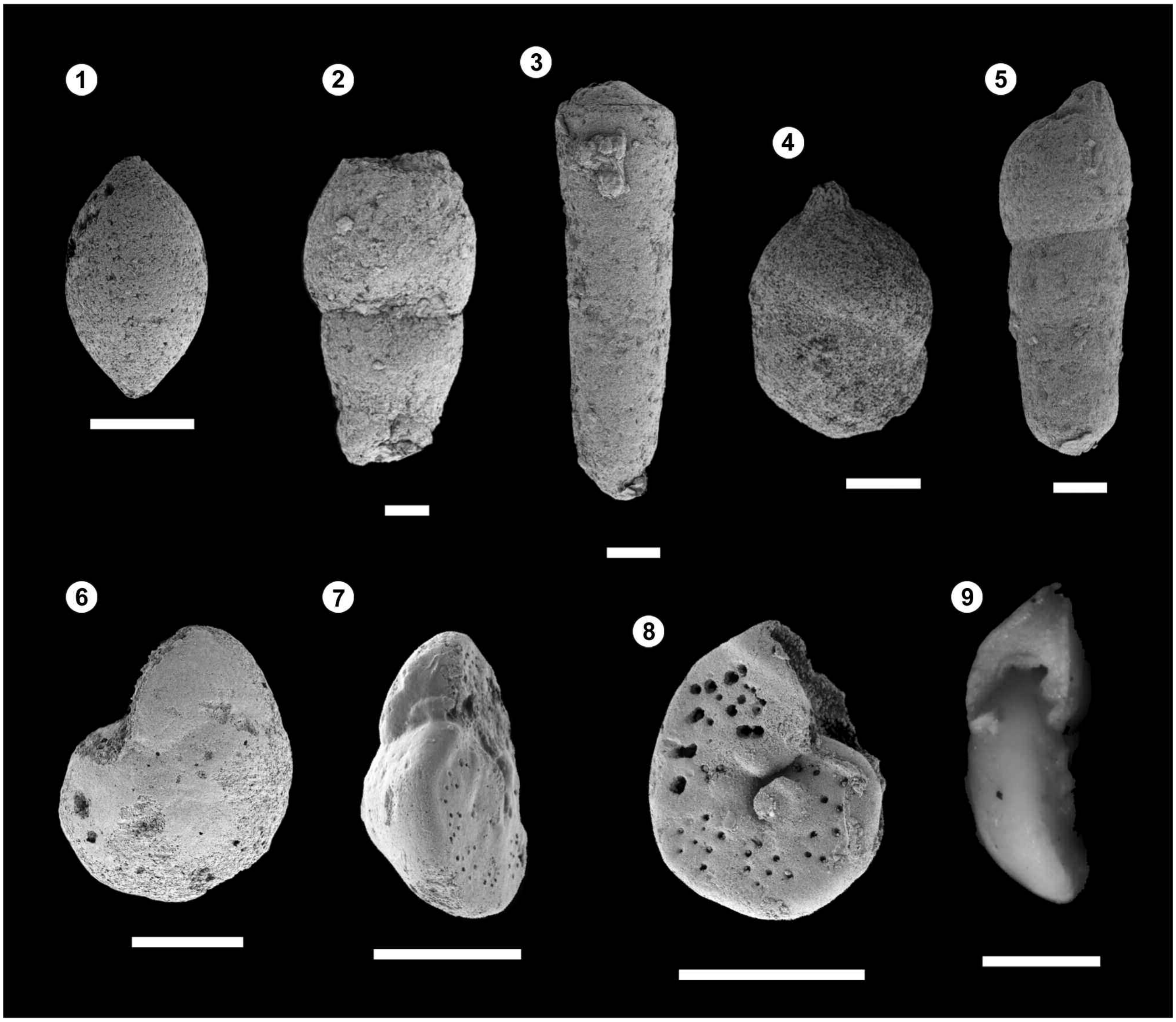


Figure 3. 1, ***Lagena*** sp. cf. ***Lagena apiculata***, Sample EC-9 (**LM-FCEN** 3726), side view. **2,** ***Lingulonodosaria*** sp., Sample EC-1 (**LM-FCEN** 3727), side view. **3,** ***Laevidentalina megalopolitana***, Sample EC-1 (**LM-FCEN** 3728), side view. **4,** ***Hemirobulina*** sp. cf. ***Hemirobulina curvatura***, Sample EC-1 (**LM-FCEN** 3729), lateral view. **5,** ***Prodentalina***? sp., Sample EC-1 (**LM-FCEN** 3730), lateral view. **6–9,** ***Gavelinella sandidgei***; **6,** Sample EC-1 (**LM-FCEN** 3733), dorsal side; **7,** Sample EC-9 (**LM-FCEN** 3734), apertural view; **8,** ventral side, Sample EC-5 (**LM-FCEN** 3735); **9,** apertural view, Sample EC-1 (**LM-FCEN** 3731). Scale bar= 100 μm. All the figures are scanning electron microscope images except Figure **9**, which is an optical image.

Superfamily Robuloidoidea
Family Ichthyolariidae Loeblich and Tappan, 1986

Genus ***Prodentalina*** Norling, 1968

Type species. *Dentalina terquemi* d'Orbigny 1850.

Prodentalina? sp.
Figure 3.5

Description. Test elongate, rectilinear, rounded in transverse section, with four overlapping chambers, externally low and slightly compressed; sutures slightly oblique, initially flush, later depressed; wall smooth, finely perforate; aperture terminal, excentric, radiate.
Remarks. The only specimen recovered from the Ekelöf Coast section differs from *Dentalina basiplanata* Cushman in having fewer chambers (four instead of 10–13) and being more robust.

Order Rotaliida
Superfamily Buliminoidea
Family Buliminellidae Hofker, 1951

Genus ***Buliminella*** Cushman, 1911

Type species. *Buliminella elegantissima* d'Orbigny, 1839.

Buliminella procera Huber, 1988

1988. *Buliminella procera* Huber, p. 199, fig. 32.5–6.
Remarks. The only specimen found in the Ekelöf Coast section was lost during an ultrasonic bath cleaning before it could be photographed; however, there is no doubt about its generic classification. Acording to Huber (1988), the species is restricted to the Danian of the *Globastica daubjergensis* Zone in the López de Bertodano Formation on Seymour Island. *Buliminella procera* is a southern hemisphere endemic species (Malumián and Caramés, 1995; Malumián and Jannou, 2010) that we observed in the Danian of Sobral Formation, Seymour Island. Other reports of *Buliminella isabelleana* Camacho forma *procera* Huber are from the Paleocene of the Estrella x-1 borehole of Colorado Basin, Argentine Continental Shelf (Caramés and Malumián, 2000) and from the Maastrichtian of the Monte Chico Formation (Malumián *et al.*, 2000), the Danian–upper Paleocene of the Cerro Dorotea Formation (Caramés, 1996; Malumián *et al.*, 2000), the upper Paleocene of the La Barca Formation (Malumián and Caramés, 2002), the early middle Eocene of the Río Bueno Formation (Malumián and Caramés, 2002) and the early Eocene of the Punta Torcida Formation (Malumián and Jannou, 2010). All the aforementioned units belong to the Austral Basin, Argentina.

Superfamily Chilostomelloidea
Family Gavelinellidae Hofker, 1956
Subfamily Gavelinellinae Hofker, 1956

Genus ***Gavelinella*** Brotzen, 1942

Type species. *Discorbina pertusa* Marsson, 1878.

Gavelinella sandidgei (Brotzen, 1936)
Figure 3.6–9

1936. *Cibicides sandidgei* Brotzen, p. 191, pl. 14, figs. 2–4.
1988. *Gavelinella sandidgei* (Brotzen). Huber, p. 206, fig. 26.17–18.
2013. *Gavelinella sandidgei* (Brotzen). Florisbal *et al.*, p. 188, fig. 4O-R.

Description. Test small, trochospiral, planoconvex, periphery subacute; dorsal side convex, with nine to10 chambers in the last whorl, sutures radial, curved and limbate, the last one depressed, the others flush especially near the central opaque and slightly elevated umbo, umbo not sorrounded by a groove; ventral side flat, slightly evolute, with one whorl visible and a deep groove obscured by triangular flap-like extensions of chambers, sutures curved, flush or depressed, limbate near the umbilicus and thinner towards the periphery; wall calcareous, the ventral side is densely perforated or with scattered coarse perforations, the dorsal side is smooth; aperture interiomarginal, a low arch at the base of the apertural face and equatorial, extending into the umbilical area under the triangular flap-like extensions of the last chambers.
Remarks. This species, frequently referred to *Cibicidoides*, was originally described as *Cibicides sandidgei* from the Campanian–Maastrichtian of Sweden. The species mainly varies in both convexity and in the size and degree of elevation of the umbo. *Gavelinella sandidgei* was recorded from the upper

Santonian–lower Campanian of the Lachman Crags Member of Santa Marta Formation on James Ross Island by Florisbal *et al.* (2013) and from the López de Bertodano Formation on Seymour Island by Huber (1988) in stratigraphic intervals assigned to the early–late Maastrichtian (Olivero, 2012a, b). Although our specimens are similar to *Cibicidoides hyphalus* (Fisher), a species described from the upper Maastrichtian of Galicia Bank, Spain, they differ from the latter in presenting a subacute periphery, a lower number of chambers and a more evolute spiral side.

Class GLOBOTHALAMEA
Subclass TEXTULARIIA
Order LITUOLIDA
Suborder HORMOSININA
Superfamily HORMOSINOIDEA
Family REOPHACIDAE Cushman, 1927

Genus ***Reophax*** de Montfort, 1808

Type species. *Reophax scorpiurus* de Montfort, 1808.

Reophax globosus Sliter, 1968

Figure 4.1–2

1968. *Reophax globosus* Sliter, p. 43, pl. 1, fig. 12.

Description. Test elongate, uniserial, rectilinear or slightly arcuate, compressed, composed of four globular chambers, somewhat overlapping, regularly increasing in size, sutures depressed; aperture terminal, rounded, on a very short neck; wall coarsely agglutinated, surface rough.

Remarks. The original description of *R. globosus*, from the Upper Cretaceous of California (United States) and Mexico, indicates its slightly arcuate test. Although our specimens are usually straight, but some of them are curved (Fig. 4.1). *Reophax troyeri* Tappan (1960) is similar to the species described from the Albian of Alaska but smaller.

Suborder LITUOLINA
Superfamily LITUOLOIDEA
Family LITUOLIDAE de Blainville, 1827
Subfamily AMMOMARGINULININAE Podobina, 1978

Genus ***Ammobaculites*** Cushman, 1910

Type species. *Spirolina agglutinans* d'Orbigny, 1846.

Ammobaculites wazaczi (Grzybowski, 1896)

Figure 4.3–4

1896. *Haplophragmium wazaczi* Grzybowski, p. 277, pl. 8, fig. 29a–b (*fide* Ellis and Messina, 1940 *et seq.*).

Description. Test elongate, compressed, greatest width of the test in the early stage, early portion planispiral, umbilicate, with four to five visible chambers, later uncoiled and rectilinear with two to five broad, low and inflated chambers; the direction of compression of the coiled and rectilinear portions is usually not coincident and the test seems distorted; sutures depressed; wall agglutinated of coarse grains; aperture terminal, rounded.

Remarks. *Ammobaculites wazaczi* was originally described from the upper Eocene or lower Oligocene of Wadowice, Poland. This species was previously recovered from stratigraphically higher strata of the Snow Hill Island Formation (named Ekelöf Ovest section in Gennari, 1997) than the levels from the Ekelöf Coast section treated herein. Liszka and Liszkowa (1981) described and illustrated the holotype of this species without mentioning the deflection of the plane of compression of the rectilinear portion relative to the plane of coiling of the planispiral stage; however, this character is distinguished from the specimen of the Upper Cretaceous of Moravia, Czech Republic, illustrated by Hanzliková (1972). In that sense, the species resembles another *Ammobaculites*, which was originally described as *Haplophragmium deplexum* Grzybowski and recovered from higher stratigraphic levels of Ekelöf Point by Gennari (1997), except for its smaller size and the more rectilinear uncoiled portion.

Superfamily RECURVOIDOIDEA
Family AMMOSPHAEROIDINIDAE Cushman, 1927
Subfamily RECURVOIDINAE Alekseychik-Mitskevich, 1973

Genus ***Recurvoides*** Earland, 1934

Type species. *Recurvoides contortus* Earland, 1934.

Recurvoides? spp.

Figure 4.5–8

Remarks. The specimens included in *Recurvoides*? spp. present a globular test, few chambers per whorl with streptospiral or streptospiral to trochospiral coiling, five or six chambers in the last whorl, eight to 12 chambers visible from the exterior, wall finely to moderately coarsely agglutinated and an aperture at the base of the last chamber that may have a bordering lip. Although the specimens may include more than one species, scarcity of well-preserved material precludes a more certain identification.

Suborder Rzehakinina
Superfamily Rzehakinoidea
Family Rzehakinidae
Subfamily Rzehakininae

Genus ***Rzehakina*** Cushman, 1927

Type species. *Silicina epigona* Rzehak, 1895.

Rzehakina minima Cushman and Renz, 1946
Figure 4.9–10

1946. *Rzehakina epigona* var. *minima* Cushman and Renz, p. 24, pl. 3, fig. 5.
1988. *Rzehakina epigona* (Rzehak). Huber, p. 191, fig. 17.8.

Remarks. *Rzehakina minima* occurs in the Campanian–early Eocene from worldwide localities (Caramés and Malumián, 2006). In Antarctica, according to Huber (1988), the species is diagnostic of the *Gaudryina healyi* Zone and occurs in low to moderate abundance in sediments from The Naze on the northeast of James Ross Island, Cape Lamb on Vega Island, the northeastern area of Snow Hill Island and the southwestern of Seymour Island. All these Antarctic exposures comprise the upper levels of the Snow Hill Island Formation. Outcrops of Seymour Island also include the lowest levels of the López de Bertodano Formation (Pirrie *et al.*, 1997a; Marenssi *et al.,* 2001; Olivero *et al.,* 2007; Olivero, 2012a,b). All the abovementioned levels were dated as early Maastrichtian (Olivero and Medina, 2000; Crame *et al.*, 2004).

Suborder Spiroplectamminina
Superfamily Spiroplectamminoidea
Family Spiroplectamminidae Cushman, 1927
Subfamily Spiroplectammininae Cushman, 1927

Genus ***Spiroplectammina*** Cushman, 1927

Type species. *Textularia agglutinans* d'Orbigny var. *biformis* Parker and Jones, 1865.

Spiroplectammina chicoana Lalicker, 1935
Figure 4.11–12

1935. *Spiroplectammina chicoana* Lalicker, p. 7, pl. 1, figs. 8, 9a–c.

Description. Test small, elongate, tapering, compressed, periphery acute, irregular in outline and acute in transverse section; early chambers planispiral, later chambers biserial, low and broad; sutures limbate, oblique, straight or slighly curved downward near peripheral margin; wall coarsely agglutinated; aperture a low arched opening at inner margin of final chamber.

Remarks. *Spiroplectammina chicoana* was originally described from the Cretaceous of California, United States.

Order Loftusiida
Suborder Loftusiina
Superfamily Loftusioidea
Family Cyclamminidae Marie, 1941
Subfamily Alveolophragmiinae Saidova, 1981

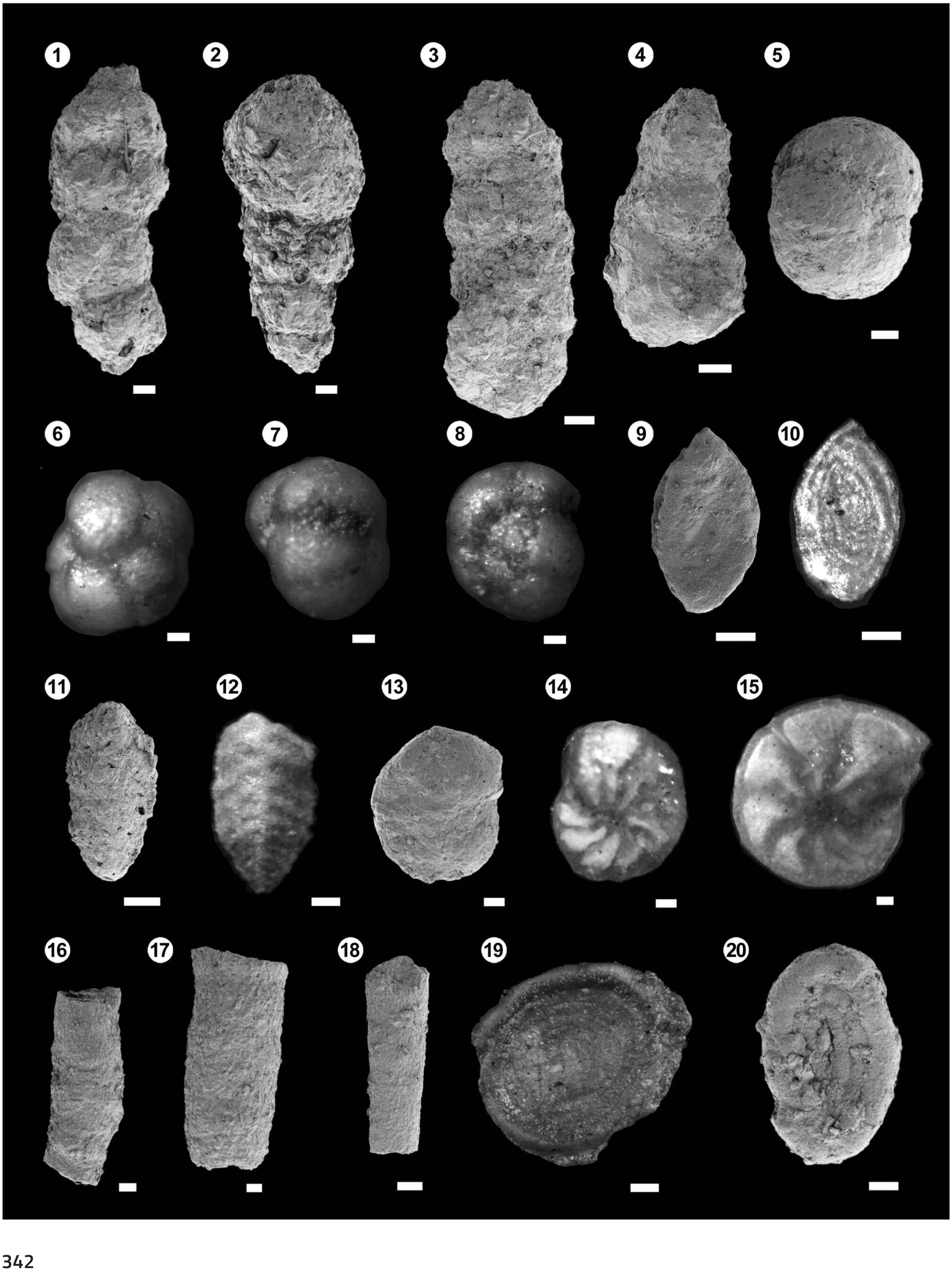
Genus ***Reticulophragmoides*** Gradstein and Kaminski, 1989

Type species. *Nonion jarvisi* Thalmann, 1932.

Reticulophragmoides jarvisi (Thalmann, 1932)
Figure 4.13–15

1932. *Nonion cretaceum* Cushman and Jarvis, p. 41, pl.12, fig. 12.
1932. *Nonion jarvisi* Thalmann, p. 313.
1988. *Haploprhagmoides* (?) *jarvisi* (Thalmann). Kaminski *et al.*, p. 190. pl. 7, figs. a–2; pl. 10, figs. 8–9.
1989. *Reticulophragmoides jarvisi* (Thalmann). Gradstein and Kaminski, p. 81, pl. 7, figs. 1–8; text-figure 4.

Description. Test biconvex, lenticular, periphery subacute, planispirally coiled, involute or partially evolute, umbilical region slightly depressed or with a thickening of clear glassy material, chambers seven to nine in final whorl, increasing gradually in size, with a tubular extension towards the umbilical region; sutures strongly limbate, flush to slightly depressed, slightly curved and with an abrupt change of direction in the middle of the lateral side or closer to the um-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bilical region because of the tubular extension of the chambers; aperture interiomarginal; wall simple, finely agglutinated.

Remarks. Neither our specimens nor those from the upper Paleocene Lizard Spring Formation, Trinidad (northeastern South America), by Gradstein and Kaminski (1989), contain any alveolus. However, according to these authors, younger specimens from the uppermost Paleocene of offshore Angola develop a few alveoles in the later chambers. Some deformed specimens, which were initially classified as *Haplaphragmoides* by Caramés *et al*. (2014), present a more rounded periphery yet perfectly match with *Reticulophragmoides jarvisi*. These deformed specimens differ from *Reticulophragmoides* sp. 5, illustrated by Gradstein and Kaminski (1989), in the absence of alveoles near the suture in the later chambers. Gradstein and Kaminski (1989) reported *Reticulophragmoides jarvisi* to be from the upper Paleocene to lower Oligocene of bathyal environments of the North Atlantic regions. It must be noted that the type specimen of *Reticulophragmoides jarvisi* (Thalmann) is *Nonion cretacea* Cushman and Jarvis, a species which was renamed as *Nonion jarvisi* by Thalmann (1932) because the name used by Cushman and Jarvis had been previously occupied. Additionally, the fact that *Nonion cretacea* Cushman and Jarvis was originally described from the Upper Cretaceous of the Pit at Lizard Springs Formation (Trinidad) yet, according to Gradstein and Kaminski (1989), Cushman and Jarvis's sample from Lizard Spring is upper Paleocene must be taken into account.

Class MONOTHALAMEA
Order ASTRORHIZIDA
Suborder ASTRORHIZINA
Superfamily ASTRORHIZOIDEA
Family RHABDAMMINIDAE Brady, 1884
Subfamily BATHYSIPHONINAE Avnimelech, 1952

Genus ***Bathysiphon*** Sars, 1872

Type species. *Bathysiphon filiformis* Sars, 1872.

Bathysiphon sp.
Figure 4.16–18

Description. Fragments tubular, short, rectilinear or irregularly bent, unbranched; transverse section varies from ovally compressed to nearly circular; wall agglutinated and fine to medium grained. The shell cavity or lumen may present a constant diameter or an irregular diameter by irregularly spaced constrictions and is always filled, fact easily visible as a white coat through the siliceous translucent wall.

Remarks. All the recovered specimens are short tubular fragments. Among the *Bathysiphon* assemblage, especially in the lower levels of the section (samples EC-1 and EC-9), there are specimens which could have been linked to the Cretaceous species *Bathysiphon brosgei* Tappan (such as the specimen illustrated in Fig. 4.16, with circular or oval transverse section and transverse growth wrinkles on the surface) and *Bathysiphon vitta* Nauss (such as the one illustrated in Fig. 4.17 with a very compressed tubular test and lumen with regular width). Yet, towards the upper levels (samples EC-13, EC-15 and EC-19), where the fragments are more abundant, there are transitional forms between these species. There, some specimens that resemble *B. vitta* present a lumen with an irregular diameter while some specimens similar to *B. brosgei* are marked by frequent constrictions which are much more flattened and with a coarser grain wall.

Figure 4. **1–2,** ***Reophax globosus*; 1,** Sample EC-15 (**LM-FCEN** 3736), lateral view; **2,** Sample EC-15 (**LM-FCEN** 3737), lateral view. **3–4,** ***Ammobaculites wazaczi*; 3,** Sample EC-15 (**LM-FCEN** 3739), lateral view; **4,** Sample EC-15 (**LM-FCEN** 3738), lateral view. **5–8,** ***Recurvoides*** sp., Sample EC-15 (**LM-FCEN** 3740); **5,** apertural view; **6,** lateral view; **7,** apertural view; **8,** lateral view. **9–10,** ***Rzehakina minima*,** Sample EC-13 (**LM-FCEN** 3741), lateral views. **11–12,** ***Spiroplectammina chicoana*; 11,** Sample EC-13 (**LM-FCEN** 3743), lateral view; **12,** Sample EC-15 (**LM-FCEN** 3742), lateral view. **13–15,** ***Reticulophragmoides jarvisi*; 13,** Sample EC-9 (**LM-FCEN** 3745), lateral view; **14,** Sample EC-1 (**LM-FCEN** 3744), lateral view; **15,** Sample EC-15 (**LM-FCEN** 3746), lateral view. **16–18,** ***Bathysiphon*** sp.; **16,** Sample EC-1 (**LM-FCEN** 3747), lateral view; **17,** Sample EC-15 (**LM-FCEN** 3748), lateral view; **18,** Sample EC-1 (**LM- FCEN** 3749), lateral view. **19,** ***Ammodiscus glabratus*,** Sample EC-15 (**LM-FCEN** 3750), lateral view. **20,** ***Ammodiscus peruvianus*,** Sample EC-15 (**LM-FCEN** 3751), lateral view. Scale bar= 100 µm. Figures **1–5, 9, 11, 13, 16–18 and 20** are scanning electron microscope images; figures **6–8, 10, 12, 14–15 and 19** are optical images.

Class Tubothalamea
Order Spirillinida
Suborder Ammodiscina
Superfamily Ammodiscoidea
Family Ammodiscidae Reuss, 1862
Subfamily Ammodiscinae Reuss, 1862

Genus ***Ammodiscus*** Reuss, 1862

Type species. *Ammodiscus infimus* Bornemann, 1874.

Ammodiscus glabratus Cushman and Jarvis, 1928
Figure 4.19

1928. *Ammodiscus glabratus* Cushman and Jarvis, p. 86, pl. 12, fig. 6a–b.

Remarks. The species is characterized by the concave, partially evolute sides and the smooth and homogeneous wall. It seems to differ from *A. cretaceous* in its smoother wall that lacks of fine radial striations. *Ammodiscus glabratus* was originally described from Lizard Spring, Trinidad (Paleocene–Eocene) and, according to Bolli *et al.* (1994), its stratigraphic range in Trinidad is early Maastrichtian to early Eocene. *Ammodiscus glabratus* was previously recovered from Ekelöf Point in younger sediments that crop out in higher stratigraphic levels of the Snow Hill Island Formation (Chorrillo Leonardo and Ekelöf Ovest sections in Gennari, 1997).

Ammodiscus peruvianus Berry, 1928
Figure 4.20

1928. *Ammodiscus peruvianu*s Berry, p. 342, pl. 27.

Remarks. Bolli *et al*. (1994) stated that, in Trinidad, compressed specimens with an elliptical outline occur throughout the range of *Ammodiscus glabratus* Cushman and Jarvis but do not include *Ammodiscus peruvianu*s Berry in their synonymy list of *A. glabratus*. *Ammodiscus peruvianu*s was originally described from the Eocene of Perú. It was also recorded in the Maastrichtian of Leg 35, southeast Pacific Basin in the Antarctic region (Rögl, 1976) and was previously recovered at Ekelöf Point from stratigraphically higher strata also belonging to the Snow Hill Island Formation at Chorrillo Leonardo and Ekelöf Ovest sections (Gennari, 1997).

Ammodiscus**?** spp.

Remarks. Specimens included herein are always finely agglutinated fragments of fairly variable size. Some specimens with adherent sediments might correspond to the genus *Glomospira*.

PALYNOMORPHS

Palynological analyses of all samples resulted in marine and continental palynomorphs with a poor to good preservation, exhibiting yellow to brown colours and some pyrite alteration. The overall composition of the assemblage is represented by spores (18–41%), pollen grains (4–17%), dinoflagellate cysts (44–76%) and remaining groups such as algae, acritarchs, organic foraminiferal linings, fungi and scolecodonts (1–2.4%). The principal continental groups are represented by bryophytes (two species), lycophytes (10 species), pteridophytes (10 species), gymnosperms (nine species), angiosperms (13 species) and chlorococcalean algae (one species). Marine palynomorphs belong to peridinacean (10 species) as well as gonyaulacacean (10 species) dinoflagellate cysts, colonial green algae (one species) and one acritarch (one species). Species are listed in Table 2 and illustrated in Figure 5.

The spore and pollen nomenclature follows that of Raine *et al*. (2011). Suggested botanical affinities of fossil spore-pollen taxa recorded in this study are based on Specht *et al*. (1992), Cieraad and Lee (2006) and Raine *et al*. (2011). The taxonomic nomenclature of dinoflagellate cysts is in accordance with Fensome *et al*. (2008). Because of bad preservation (mainly broken and degraded specimens), some dinoflagellate cyst species were not easy to identify and therefore grouped under the denomination “dinocyst spp. indet.”. Some taeniate bisaccate pollen grains recognized in the analyzed samples are interpreted as reworked (probably from Permian Antarctic Peninsula sediments) and thus not classified but counted as reworked pollen.

AGE CONSTRAINTS

Sumner (1992) analyzed the dinoflagellate cyst assemblage recovered from 17 samples corresponding to the lower 34.5 m exposed at Ekelöf Point and determined its age as middle to late Campanian. Following Crame *et al*.

(1991), Sumner (1992) considered this exposure as part of the Rabot Member of the Santa Marta Formation. Yet, such postulation was later corrected by Pirrie *et al*. (1997a), who correlated Ekelöf strata with their Herbert Sound Member of the Santa Marta Formation. Ekelöf strata were later considered equivalent to both the Gamma (approximately akin to the Herbert Sound Member) and Hamilton Point members of the Snow Hill Island Formation by Olivero (fig. 1 in 2012a,b).

Pirrie *et al*. (1997a) analyzed the palynology of three samples from different stratigraphical positions at Ekelöf Point; one located at the base of the section, another in the middle and the last one at the top. The only sample coinciding with one stratigraphic horizon within our Ekelöf Coast section is the stratigraphically lowest one (sample DJ.679.1 in Fig. 7), assigned as middle Campanian by Pirrie *et al*. (1997a).

Considering ammonite evidence, Pirrie *et al*. (1997a) indicated that the baculitid ammonites recorded at the base of the Ekelöf Point section are referable to *Baculites rectus* Marshall, a species which was previously recorded in the Lachman Crags Member, northern James Ross Island, as early to mid-Campanian. Recently, the baculitids recorded at the bases of the Ekelöf Coast section, Hamilton Point Member at Hamilton Point and the Gamma Member at Santa Marta Cove were referred to *Baculites delvallei* Riccardi (Olivero, 2012b). According to this author, both the Hamilton Point Member and the Gamma Member are stratigraphically situated at the base of the Snow Hill Island Formation, which initiated the NG Sequence during the late Campanian–early Maastrichtian (Olivero, 2012a,b).

In the present study, the foraminiferal assemblage recovered proves diverse although only 10 out of the 18 taxa have been determinated at specific level. Five of these 10 were originally described from the Upper Cretaceous of Europe and/or North America. *Ammobaculites wazaczi*, *Buliminella procera, Ammodiscus glabratus* and *A. peruvianus,* originally described from Paleogene sediments, are commonly recorded in the Upper Cretaceous all over the world. Nevertheless, none of the species herein recorded can be used as diagnostic markers because of their long-ranging stratigraphic ranges (Tab. 1). Among the species previously cited, in West Antarctica, *Gavelinella sandidgei, Laevidentalina megalopolitana*, *Hemirobulina* sp. cf. *Hemirobulina curvatura* and *Rzehakina minima* should be mentioned. These species were previously recognized by Huber (1988) in the James Ross Basin from the younger López de Bertodano Formation, at present dated as early–late Maastrichtian (Olivero, 2012a).

Gavelinella sandidgei was also recorded at the Lachman Crags Member of the Santa Marta Formation (upper Santonian–lower Campanian) by Florisbal *et al.* (2013). Regarding *Buliminella procera* Huber, although it had initially been thought to be restricted to the Danian *Globastica daubjergensis* Zone in the López de Bertodano Formation, Seymour Island (Huber, 1988), it was later reported in southern South America from the Maastrichtian to the lower Eocene (see Systematic Paleontology).

To our knowledge, *Reticulophragmoides jarvisi* was previously recorded from the late Paleocene to the early Oligocene of low latitudes. The presence of this species in the herein studied samples indicates that this is the oldest known record in Antarctica and the first reported at high latitudes.

In order to obtain a more accurate age the dinoflagellate cysts assemblage was also analysed. The assemblage contains long-ranging taxa, *e.g.*, *Spiniferites ramosus* and *Trichodinium castanea*, that spans the whole Late Cretaceous (Fensome *et al*., 2008).

Dinoflagellate index species with stratigraphic significance include *Isabelidinium cretaceum*, which is recorded from the middle Santonian to the early Maastrichtian of Australia (Helby *et al*., 1987) and from the middle Santonian to the late Campanian of New Zealand (Raine and Schiøler, 2012). In Australia and New Zealand, the modern American tripartite division of the Campanian Stage is resorted to and such demarcation was adopted by several palynologists who have worked on Antarctic localities (Dolding, 1992; Smith, 1992; Wood and Askin, 1992). Antarctic records of *Isabelidinium cretaceum* are known from the middle to the late Campanian of Humps Island (Dolding, 1992; Wood and Askin, 1992), from the latest Campanian–earliest Maastrichtian of Vega Island (Smith, 1992) and, on Seymour Island and according to Bowman *et al*. (2012), the last appearance datum (LAD) or range top of this species is the ?late Maastrichtian.

Isabelidinium pellucidum spans from the middle Campanian to the early Maastrichtian in Australia (Helby *et al*.,

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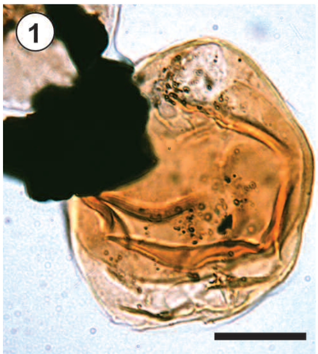

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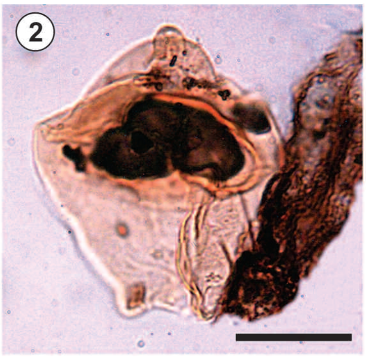

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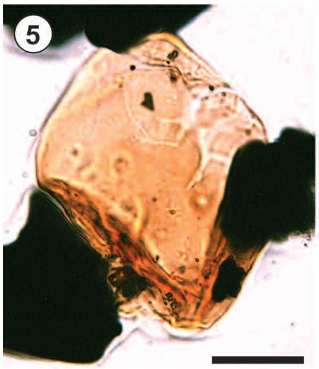

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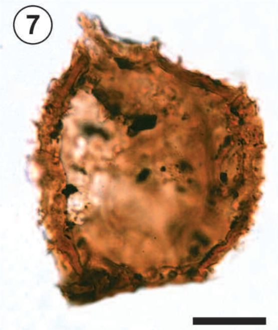

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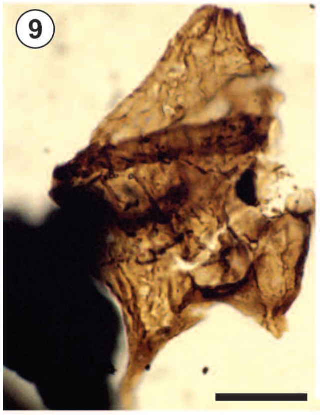

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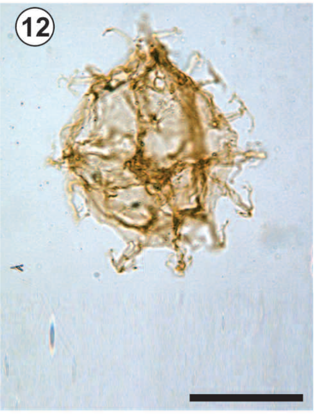

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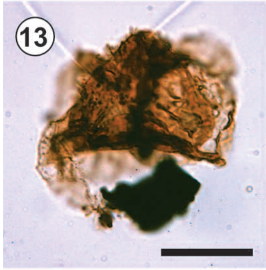

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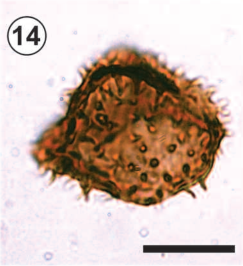

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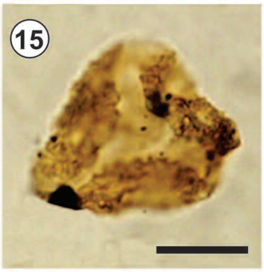

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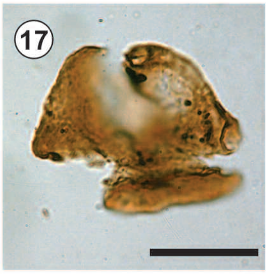

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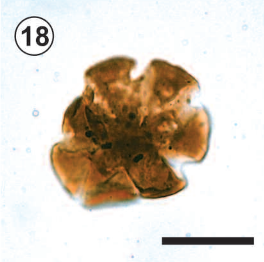

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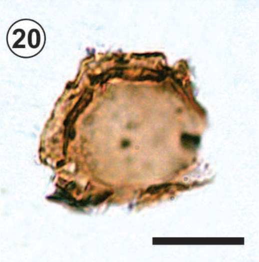

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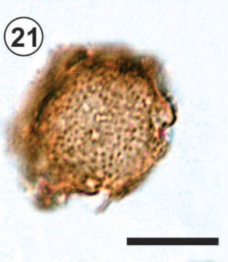

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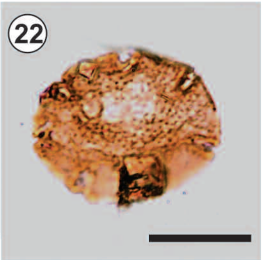

1987) and from a late Campanian to a late Maastrichtian in New Zealand (Raine and Schiøler, 2012). In Antarctica, this species is recorded in the middle–late Campanian of Humps Island (Dolding, 1992; Wood and Askin, 1992) and in the latest Campanian–earliest Maastrichtian of Vega Island (Smith, 1992). On Seymour Island, the species is recorded in the ?late Maastrichtian and does not extend its stratighraphic range to younger strata (Bowman *et al.*, 2012).

Odontochitina is a common genus in palynofloras from the early Santonian to early Maastrichtian of Australia (Helby *et al.*, 1987) and New Zealand (Raine and Schiøler, 2012). In Antarctica, species of *Odontochitina* are also frequent in assemblages that span from the Santonian to the earliest Maastrichtian but they have not been observed in the late Maastrichtian–early Danian sections (Bowman *et al.*, 2012).

Phelodinium magnificum ranges from the Campanian to the late Maastrichtian worldwide (Fensome *et al.*, 2008) but, in Antarctica, the first occurrence of this species, registered as *Phelodinium* sp. cf. *P. magnificum*, occurs within the latest Maastrichtian to earliest Danian of Seymour Island (Bowman *et al.*, 2012). Although the species boasts a younger record, Sumner (1992) recognized it in Ekelöf Point and highlighted the diachronism of this taxon in the James Ross Basin.

Tanyosphaeridium xanthiopyxides is registered for the latest Maastrichtian of New Zealand (Raine and Schiøler, 2012) and the ?late Maastrichtian of Seymour Island (Bowman *et al.*, 2012). However, at Humps Island, this species occurs in the late Campanian (Dolding, 1992).

While *Amphidiadema denticulata* is recorded in the middle to late Santonian of Australia (Helby *et al.*, 1987), in Antarctica, it is registered in the late Campanian of Humps Island (Dolding, 1992).

Sumner (1992) defined *Isabelidinium papillum* at Ekelöf Point and assigned the assemblage to the middle to late Campanian. This species was later registered in the late Campanian of New Zealand (Raine and Schiøler, 2012).

Laciniadinium biconiculum is a middle Campanian species recorded around the North Hemisphere (Fensome *et al.*, 2008) and in the Southern Indian Ocean (Williams *et al.*, 2004). In both regions, palynological studies follow the Campanian tripartite division.

Manumiella seymourensis is known as a typical Maastrichtian form. Its age is restricted to the ?late Maastrichtian and their first appearance datum (FAD) and last appearance datum (LAD) define the *Manumiella seymourensis* Range Zone (Bowman *et al.*, 2012) on Seymour Island. However, the species has also been found in older sediments; for example, it was registered in the latest Campanian–earliest Maastrichtian on Vega Island (Smith, 1992) as *Manumiella* n. sp. 3 of Askin (1988). In the assemblage studied herein, few specimens presenting a morphology comparable to *M. seymourensis* were observed and, as their endocysts were not easily visible, they were assigned to *Manumiella* sp. cf. *M. seymourensis* (Fig. 5.5–6).

As evidenced by the abovementioned statements, there is considerable disparity in the stratigraphical range of the species at the James Ross Basin, Australia and New Zealand. Nevertheless, taking into account the stratigraphical Antarctic ranges of the index species, we would place the Ekelöf assemblage in the late Campanian–earliest Maastrichtian, following the tripartite division of the Campanian. Such age is supported by the common co-occurrence of *Isabelidinium pellucidum* and *Isabellidinium cretaceum*, together

Figure 5. 1, ***Isabelidinium cretaceum*****,** Sample EC-19 (**BAFC-Pl** 2446-2, M47/2). **2,** ***Isabelidinium papillum*****,** Sample EC-9 (**BAFC-Pl** 2444-2, K46/4). **3,** ***Isabelidinium pellucidum*****,** Sample EC-1 (**BAFC-Pl** 2443-2, X54/3). **4,** ***Amphidiadema denticulata*****,** Sample EC-9 (**BAFC-Pl** 2444-2, T32). **5–6,** ***Manumiella*** sp. cf. ***M. seymourensis*****; 5,** Sample EC-19 (**BAFC-Pl** 2446-2, Z38/1); **6,** Sample EC-19 (**BAFC-Pl** 2446-2, M55). **7,** ***Trichodinium castanea*****,** Sample EC-15 (**BAFC-Pl** 2445-2, S45/4). **8,** ***Impagidinium*** sp., Sample EC-19 (**BAFC-Pl** 2446-2, Q36/3). **9,** ***Phelodinium magnificum*****,** Sample EC-9 (**BAFC-Pl** 2444-1, F41). **10,** ***Laciniadinium***? ***biconiculum*****,** Sample EC-1 (**BAFC-Pl** 2443-2, Q37/4). **11,** ***Tanyosphaeridium xanthiopyxides*****,** Sample EC-1 (**BAFC-Pl** 2443-2, K33). **12,** ***Spiniferites ramosus*****,** Sample EC-1 (**BAFC-Pl** 2443-1, V50/3). **13,** ***Evansispora senonica*****,** Sample EC-19 (**BAFC-Pl** 2446-2, C55/3). **14,** ***Ceratosporites equalis*****,** Sample EC-15 (**BAFC-Pl** 2445-1, T36/2). **15,** ***Trichotomosulcites subgranulatus*****,** Sample EC-1 (**BAFC-Pl** 2443-2, 35/0). **16,** ***Phyllocladidites mawsonii*****,** Sample EC-19 (**BAFC-Pl** 2446-2, Z41/1). **17,** ***Peninsulapollis gillii*****,** Sample EC-1 (**BAFC-Pl** 2443-1, Q54). **18,** ***Polycolpites langstonii*****,** Sample EC-19 (**BAFC-Pl** 2446-2, G43). **19,** ***Tricolpites*** sp. cf. ***T. lilliei*****,** Sample EC-1 (**BAFC-Pl** 2443-2, U35). **20–21*****, Nothofagidites senectus*****,** Sample EC-15 (**BAFC-Pl** 2445-1, C33/3). **22,** ***Nothofagidites kaitangataensis*****,** Sample EC-15 (**BAFC-Pl** 2445-2, S43). Scale bar= 20 μm.

Table 2 – Palynomorphs recovered from Ekelöf Coast section, listed in major categories and with their biological affinities (Order or family).

Species	*Affinity*	*Fig.*
Dinoflagellate cysts		
Amphidiadema denticulata	*Peridiniales*	*5.4*
Chatangiella *sp.*	*Peridiniales*	
Impagidinium *sp.*	*Gonyaulacales*	*5.8*
Impletosphaeridium clavus	*Gonyaulacales*	
Isabelidinium cretaceum	*Peridiniales*	*5.1*
Isabelidinium papillum	*Peridiniales*	*5.2*
Isabelidinium pellucidum	*Peridiniales*	*5.3*
Isabelidinium *spp.*	*Peridiniales*	
Laciniadinium*?* **biconiculum**	*Peridiniales*	*5.10*
Manumiella *sp. cf.* **M. seymourensis**	*Peridiniales*	*5.5–6*
Odontochitina *spp.*	*Gonyaulacales*	
Oligosphaeridium *sp.* ***A*** *(in Sumner, 1992)*	*Gonyaulacales*	
Operculodinium *spp.*	*Gonyaulacales*	
Phelodinium magnificum	*Peridiniales*	*5.9*
Phelodinium *spp.*	*Peridiniales*	
Spiniferites ramosus	*Gonyaulacales*	*5.12*
S. ramosus ***subsp.*** **multibrevis**	*Gonyaulacales*	
Spiniferites *spp.*	*Gonyaulacales*	
Tanyosphaeridium xanthiopyxides	*Gonyaulacales*	*5.11*
Trichodinium castanea	*Gonyaulacales*	*5.7*
Dinocyst spp. indet.		
Algae and acritarch		
Botryococcus *sp.*	*Chlorococcales*	
Palambages *sp.*	*Green algae*	
Paralecaniella indentata	*Algae or acritarch*	
Spores		
Aequitriradites baculatus	*Bryophyta*	
Aequitriradites *sp. cf.* **A. spinulosus**	*Bryophyta*	
Baculatisporites comaumensis	*Osmundaceae*	
Ceratosporites equalis	*Lycopodiaceae*	*5.14*
Ceratosporites masculus	*Lycopodiaceae*	
Cicatricosisporites *sp.*	*Schizaeaceae*	
Cyathidites australis	*Cyatheaceae*	
Cyathidites *spp.*	*Cyatheaceae*	
Evansispora senonica	*Lycopodiaceae*	*5.13*
Gemmatriletes *sp.*	*Grammitidaceae*	
Gleicheniidites senonicus	*Gleicheniaceae*	

TABLE 2 – Continuation.

Species	*Affinity*	*Fig.*
Laevigatosporites ovatus	*Blechnaceae*	
Leptolepidites verrucatus	*Isoetaceae*	
Osmundacidites wellmanii	*Osmundaceae*	
Perotrilites majus	*Selaginellaceae?*	
Perotrilites *sp. cf.* **P. granulatus**	*Selaginellaceae?*	
Perotrilites *spp.*	*Selaginellaceae?*	
Perotriletes pannuceus	*Selaginellaceae?*	
Retitriletes austroclavatidites	*Lycopodiaceae*	
Retitriletes nodosus	*Lycopodiaceae*	
Ruffordiaspora australiensis	*Schizaeaceae*	
Gymnosperm pollen		
Araucariacites australis	*Araucariaceae*	
Araucariacites *sp.*	*Araucariaceae*	
Gamerroites *sp.*	*Podocarpaceae*	
Microcachryidites antarcticus	*Podocarpaceae*	
Phyllocladidites mawsonii	*Podocarpaceae*	*5.16*
Phyllocladidites *sp.*	*Podocarpaceae*	
Podocarpidites marwickii	*Podocarpaceae*	
Podocarpidites *spp.*	*Podocarpaceae*	
Trichotomosulcites subgranulatus	*Podocarpaceae*	*5.15*
Angiosperm pollen		
Liliacidites variegatus	*Liliaceae*	
Nothofagidites brassii *type*	*Nothofagaceae*	
Nothofagidites dorotensis	*Nothofagaceae*	
Nothofagidites kaitangataensis	*Nothofagaceae*	*5.22*
Nothofagidites senectus	*Nothofagaceae*	*5.20–21*
Peninsulapollis askiniae	*Proteaceae*	
Peninsulapollis gillii	*Proteaceae*	*5.17*
Polycolpites langstonii	*Polygalaceae*	*5.18*
Proteacidites scaboratus	*Proteaceae*	
Proteacidites *sp.*	*Proteaceae*	
Tricolpites *sp. cf.* **T. lilliei**	*Ranunculaceae*	*5.19*
Tricolporites *spp.*	*Numerous families*	
Triorites *sp. cf.* **T. minor**	*Proteaceae*	
Reworked taeniate bisaccate pollen	*Gymnospermae*	
Miscellanea		
Fungal mycelium	*Fungi*	
Scolecodont	*Annelida*	
Foraminifera organic linings	*Foraminifera*	

with *Odontochitina* spp. and the presence of *Tanyosphaeridium xanthiopyxides.* Nonetheless, the assemblage is most likely late Campanian in age because of *Amphidiadema denticulata*, which has been registered up to this stage in Antarctica.

Distinctive early–middle Campanian taxa of Australia and New Zealand (*e.g.*, *Nelsoniella aceras, Nelsoniella tuberculata*, *Satyrodinium haumuriense*; see Raine and Schiøler, 2012), which have been reported in other localities of the James Ross Basin (Rabot Formation, in Palamarczuk *et al.*, 1990; Pirrie *et al.*, 1997a), have not been found in the studied assemblage and, therefore, a younger age than that of the latter species aforementioned is suggested. The fact that the assemblage can reach the earliest Maastrichtian because of the occurrence of *Manumiella* sp. cf. *M. seymourensis* in some of the levels is not excluded.

In this assemblage, there are some species with biostratigraphic significance; yet, a direct comparison with zonation schemes of Australia and New Zealand is difficult because of their strongly provincial nature and the low species diversity of the Ekelöf assemblage.

In reference to the continental palynomorphs, almost all of the pollen and spore species present long stratigraphical ranges that include the Late Cretaceous and Paleocene of the Southern Hemisphere (Raine *et al.*, 2011). The only taxon that is marked by a more restricted range is the pollen species *Tricolpites lilliei*. This species ranges from the middle Campanian to the end of the Maastrichtian in New Zealand and its FAD defines the base of the PM2 miospore zone of Raine (see Raine and Schiøler, 2012). In Australia, *Tricolpites lilliei* defines the base of the *Tricolporites lilliei* (now *Tricolpites lilliei,* see Raine *et al.,* 2011) Oppel Zone of the middle Campanian to the early Maastrichtian and continues throughout the contiguous *Tricolpites longus* Oppel Zone, dated as latest early to late Maastrichtian to possibly basal Danian (Helby *et al.*, 1987).

According to Helby *et al.* (1987), the difference between the two zones, besides the index species of each area, is the relative abundance of the *Nothofagidites* species. While within *Tricolporites lilliei* Oppel Zone, *Nothofagidites* spp. is abundant, in the overlying *Tricolpites longus* Oppel Zone, the species of *Nothofagidites* show a decrease concurrence with an increase of angiosperm grains. The Ekelöf assemblage presents a common occurrence of *Nothofagidites* species (17 to 50% of the total pollen population) of which the *Nothofagidites brassii* type proves the most common.

In the assemblage studied herein, the presence of *Tricolpites* sp. cf. *T. lilliei* (confer is used here for this pollen grain specimen whose apertures are not well marked) together with common *Nothofagidites* spp. enables its correlation with the *T. lilliei* Zone Oppel Zone of Australia, dated as middle Campanian to early Maastrichtian.

In summation, the age of the Hamilton Point Member at the Ekelöf Coast section is late Campanian to earliest Maastrichtian in terms of the Campanian tripartite division and based on dinoflagellate cysts and continental palynomorphs. Considering that the modern middle Campanian in the tripartite subdivision is approximately equivalent to the base of the classical European late/upper Campanian in the bipartite division, the Ekelöf Coast section is included within the upper part of the NG sequence (late Campanian to early Maastrichtian) of Olivero (2012b), who follows a bipartite division of the Campanian Stage.

PALEOENVIRONMENTAL INFERENCES

Foraminiferal Assemblages

The six studied samples yielded foraminifers that indicate fully marine conditions. A total of 18 benthic foraminiferal taxa were recognized, 10 agglutinated of medium size and eight calcareous with small, thin and smooth tests. Species richness varies between two and 10 species and their abundance, between six and 124 individuals per sample (Tab. 1). Because of the low species diversity and abundance and the fact that few samples were analyzed in this study, the following paleoenvironmental inferences are tentative and approximate.

Test preservation is poor to moderate. Some foraminifera are flattened (*e.g.*, *Reophax globosus*) and others are fragmented (*e.g.*, trochospiral forms such as *Gavelinella sandidgei* that have lost their last chamber, and elongated and cylindrical forms such as *Bathysiphon* spp., *Lingulonodosaria* sp. and *Laevidentalina megalopolitana* that are broken). Consequently, resedimentation or transport before burial has not been excluded. Additionally, all calcareous specimens present a dull and rough appearance because of strong dissolution.

Except for sample EC-5, which is extremely poor with only six specimens belonging to two calcareous species (Tab. 1), the rest of the samples are dominated by agglutinated tests (between 77–100%). The samples EC-1, EC-9 and EC-13 present low percentages of calcareous benthic foraminifera (0.3-22.9). Their assemblages probably represent impoverished, dissolution-resistant calcareous microfauna. The presence of some dissolution-resistant calcareous benthic foraminifera indicates sedimentation in depths above the calcium carbonate compensation depth as well as extremely low calcium carbonate availability in the water column and water/sediment surface. The upper part of the section where the samples EC-15 EC-19 were taken, is barren as regards foraminifera.

Although some authors, such as Buzas *et al.* (1993), consider microhabitat interpretation based on morphogroup assignments to be simplistic, the impoverished assemblage recovered prevents its analysis by means of any other methods. The widespread idea about utilizing the distribution of morphogroups as indicator of paleoenvironmental changes is based on: a) the assumption that there are relationships between form and function; b) that modern assemblages segregate their environment vertically into a number of separate niches based upon feeding strategies which depend on environmental factors; and c) that test morphology is a characteristic rarely obliterated by taphonomic processes (dissolution, diagenesis). Paleoecological modes of life for agglutinated foraminifera and agglutinated foraminifera morphogroups were inferred following van der Akker *et al.* (2000), Nagy *et al*. (1995), Kaminski and Gradstein (2005) and Cetean *et al.* (2011). The genus *Reticulophragmoides* was considered a surficial epifaunal and/or shallow infaunal form due to its rounded planispiral morphology and its similarity to *Haploprhagmoides.* Considerations on calcareous foraminiferal morphogroups were based on previous literature (Koutsoukos and Hart, 1990; Cetean *et al.,* 2011).

According to shell morphology, we distinguished six agglutinated and three calcareous foraminiferal submorphogroups (Tabs. 3–4). The relative abundances of these morphogroups can provide some insight regarding paleoenvironmental conditions.

In samples EC-1, EC-9 and EC-13, the agglutinated assemblage is dominated by tubular erected epifaunal forms (*Bathysiphon* spp.). Up-section, the dominant agglutinated morphotypes change. The assemblage obtained from the sample EC-15 is dominated by elongate keeled surficial epifaunal forms (*Spiroplectammina chicoana*) followed by tubular erected epifaunal forms (*Bathysiphon* spp.). In the sample EC-19, the elongate tapered deep infaunal (represented by *Reophax globosus*) and the tubular erect epifaunal forms (*Bathysiphon* spp.) appear in equal proportions and are followed by less abundant elongate keeled surficial epifaunal forms (*Spiroplectammina chicoana*).

The frequent occurrences of *Bathysiphon* (in all samples except for EC-5) and the common records of *Gavelinella sandidgei* from the lower samples (EC-1 to EC-13) suggest an outer shelf-upper bathyal environment. Also, samples EC-1 to EC-13 present abundant epifaunal and shallow infaunal forms that may reflect mesotrophic and oxic conditions in which the bulk of labile organic matter is consumed in the surface (in the photic zone) and the scarce material that reaches the seafloor is consumed, among other organisms, by foraminifera epifauna and particularly by suspension feeding tubular erected morphotypes (*Bathysiphon* spp.).

In sample EC-15, the high relative abundance of *Spiroplectammina,* a genus regarded as an active deposit feeder that lives at or just below the sediment surface (surficial epifauna) in shallow water environments (shelf to marginal marine), along with *Bathysiphon*, a tubular passive suspen-

Table 3 – Calcareous benthic foraminifera morphogroups used in this study (modified after Cetean* et al., *2011).

Morphogroup	*Sub-Morphogroup*	*Test form*	*Life position*	*Feeding habit*	*Genera*
CH-A	*2*	*Planoconvex trochospiral*	*Epifauna*	*Active deposit feeding*	**Gavelinella**
CH-B	*1*	*Cylindrical*	*Infauna*	*Deposit feeding*	*Nodosarids* **Hemirobulimina**
	4	*Pyramidal to conical*	*Infauna*	*Active deposit feeding*	*Lagenids (elongated forms)* **Buliminella**

TABLE 4 – Agglutinated benthic foraminifera morphogroups used in this study (modified after Cetean et al.*, 2011).*

Morpho-group	*Test form*	*Life position*	*Feeding habit*	*Environment*	*Genera*
M1	*Tubular*	*Erect epifauna*	*Suspension feeding*	*Tranquil bathyal and abyssal with low organic flux*	**Bathysiphon**
M2b	*Rounded trochospiral and streptospiral*	*Surficial epifauna*	*Active deposit feeding*	*Shelf to deep marine*	**Recurvoides**
M2c	*Elongated keeled*	*Surficial epifauna*	*Active deposit feeding*	*Shelf to marginal marine*	**Spiroplectammina**
M3a	*Flattened planispiral And streptospiral*	*Surficial epifauna*	*Active and passive deposit feeding*	*Lagoonal to abyssal*	**Ammodiscus** **Rzehakina**
M4a	*Rounded planispiral*	*Surficial epifauna and/or shallow infauna*	*Active deposit feeding*	*Inner shelf to upper bathyal*	**Reticulophragmoides**
M4b	*Elongated tapered*	*Deep infauna*	*Active deposit feeding*	*Inner shelf to upper bathyal with increased organic matter flux*	**Reophax** **Ammobaculites**

sion feeder whose life position is embedded in soft sediments (erect epifauna) of outer neritic to bathyal environments, may be interpreted as a possible decrease in water-depth or a down-slope transport of the shelf foraminifera fauna. Additionally, in sample EC-15, the increasing taxa abundance and the occurrence of deep infaunal forms may be interpreted as, in comparison to samples from lower stratigraphic levels, a response to higher supplies of organic matter. As suggested by the increase of deep infaunal forms in sample EC-19, this organic matter enrichment continues upwards. In this very sample, the increase of deep infaunal taxa, more tolerant to dysoxic conditions, together with a decrease of species diversity and abundance, might suggest bottom waters under more marked eutrophic conditions.

Palynological Assemblage

The palynological analyses of all samples provided abundant dinoflagellate cysts, spores and pollen in variable percentages along the whole section (Tab. 2). The dinocyst assemblage is dominated by peridiniacean taxa among which the most abundant peridinioid species is *Isabelidinium cretaceum* and specimens assigned to *Isabelidinium* spp. Dinoflagellate cysts display low diversity while a total of 20 species were identified of which some have been left in open nomenclature. Regarding the continental palynomorphs, trilete spores dominate over pollen grains at all levels. Twenty-two spore species (five species are left in open nomenclature) and 22 pollen species (six species are left in open nomenclature) were identified in total (Tab. 1). A terrestrial influx is present at all levels.

For the marine environment, both the S/D ratio (Versteegh, 1994) and the P/G cyst ratio (Harland, 1973) were employed, in concert, for deducing the depositional environment. Sporomorph *vs.* dinocyst ratio (S/D) is calculated as follows: $S/D = nS/(nD + nS)$ where n is the number of counted specimens, S is represented by pollen and spores and D, by dinocysts and marine acritarchs; whereby an increase in pollen and spores relative to dinocysts is interpreted as a sea level lowering as the section becomes more proximal to the coast. In the P/G cyst ratio, P is the number of peridinoid species and G, the gonyaulacoid species (Sluijs *et al.*, 2005). This concept is used to identify paleoproductivity trends based on feeding strategies of most peridinioid and gonyaulacoid dinoflagellates (Sluijs *et al.*, 2005). High P/G values are associated to significant freshwater input. Thereby, a peridinoid-dominated assemblage reflects low salinity and nutrient-rich conditions and is related to coastal and inner neritic environments (lagoonal, brackish water). In contrast, low values of the P/G, *i.e.*, gonyaulacoids-dominated assemblages, indicate offshore or open marine environments. This is due to the assumption that P-cysts are considered to predominantly represent heterotrophic dinoflagellates that primarily thrive on diatoms whereas G-cysts mainly represent autotrophic dinoflagellates.

In the Ekelöf samples, the S/D ranges from 0.4 to 0.7, revealing that there are no large variations along the section. As for the P/G cyst ratio, ranges between 1 and 1.8 indicate that the number of peridinoid cysts species is equal to or greater than that of gonyaulacoid cysts species. Considering both ratios, it is observed that there was a continuous supply of material sourced from the continent to the marine environment and peridionoids slighty dominate over gonyaulacoids dinoflagellate cysts, a condition normally interpreted as corresponding to a coastal and inner neritic environment.

DISCUSSION

The paleoenvironmental interpretation based on morphogroups of foraminifera indicates an outer shelf-upper bathyal environment in agreement with sedimentological data (Robles Hurtado *et al.*, 1997). In contrast, the permanent terrestrial influx and the peridinoid cysts dominance over gonyaulacoids are commonly interpreted as indicatives of shallow-water conditions. Sumner (1992) had already pointed out this discrepancy between palynological and sedimentological data and suggested that adverse paleoenvironmental conditions other than water depth *per se* may have affected the dinoflagellate cyst assemblages.

Taking into account the dinoflagellate cysts species recognized in the assemblage, the presence of the gonyalaucoid genus *Impagidinium* in the upper level (EC-19) is noteworthy (Tab. 1, Fig. 5). In spite of having registered a single specimen not been possible to identify to identify at a specific level, the genus *Impagidinium* is indicative of outer neritic to oceanic settings (Sluijs *et al.*, 2005). This suggests that taxa of different environments were deposited together. The dominance of peridinacean cysts and continuous terrigenous input with some open marine dinoflagellate cysts can be explained by the existence of a narrow continental shelf with terrestrial palynomorphs and P-cysts being quickly transported down the slope and deposited in a deeper marine environment where the mixing with G-cysts occurs. The presence of outer neritic to open marine taxa (such as *Impagidinium*) in the upper level (EC-19), which is interpreted a sea level rise (Sluijs *et al.*, 2005), conforms with paleoenvironmental inferences previously suggested for the section by Robles Hurtado *et al.* (1997) and with the transgressive offshore settings envisaged by Olivero (2012a,b) on the basis of sequence stratigraphical analysis.

The mixed shallow and deeper water taxa detected in dinoflagellate cysts is also observed in foraminifera. The presence of *Spiroplectammina*, a genus characteristic of deeper shelf and marginal marine environments, is an evidence of such mixture. Moreover, the absence of any planktonic foraminfera, the dominance of agglutinated foraminifera and the prevalence of low species diversity together with low abundance may be interpreted as suggestive of a middle shelf setting. However, taking into account the consistent presence of *Bathisyphon*, the probable post-depositional solution and the sedimentological interpretation of this section (see Robles Hurtado *et al.*, 1997), we believe that our interpretation is more suitable. To conclude, in this work, the foraminifera assemblage recovered from the Ekelöf Coast section has demonstrated to be more useful for determining paleoenvironmental settings.

The index P/G would prove limited when cysts preservation is not good. In the analysis presented herein, there are several specimens that were grouped into the category "dinocyst spp. indet" because of their poor preservation. This fact would modify the value of P/G since this ratio considers the number of species but not that of specimens (Sluijs *et al.*, 2005). Thus, the values of P or/and G can be underestimated as regards their influence over the paleoenvironmental interpretation.

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