· **Review** · **Advances in Polar Science**
doi: 10.13679/j.advps.2019.0017 September 2019 Vol. 30 No. 3: 165-185

Mesozoic and Cenozoic microbiotas from eastern Antarctic Peninsula: adaptation to a changing palaeoenvironment

Cecilia R. AMENÁBAR[1,2,3*], Andrea CARAMÉS[1], Susana ADAMONIS[1,2], Ana DOLDAN[1], Gabriel MACEIRAS[2] & Andrea CONCHEYRO[1,2,3]

[1] Instituto de Estudios Andinos "Don Pablo Groeber". Consejo Nacional de Investigaciones Científicas y Técnicas. Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires. Pabellón II. Ciudad Universitaria. CP 1428. Ciudad Autónoma de Buenos Aires, Argentina;
[2] Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Argentina;
[3] Instituto Antártico Argentino, 25 de Mayo 1151, 3 piso. CP 1650. San Martín, Buenos Aires, Argentina

Received 13 March 2019; accepted 6 July 2019; published online 30 July 2019

Abstract A compiled selected literature on some groups of microfossils of the Mesozoic and Cenozoic of the James Ross Basin, eastern Antarctic Peninsula, is presented here, in order to show how the microbiota has been modified over time, triggered by environmental changes. The analyzed microfossils consist of palynomorphs (mostly pollen grains, spores, and dinoflagellate cysts), foraminifers and bryozoans. Dinoflagellate cysts and pollen-spores have been recorded in Jurassic to Pleistocene sedimentary outcrops. Dinoflagellate cysts proved to be good indicators for productivity and/or nutrient availability, surface water temperature and chemistry, the position of ancient shorelines and paleoceanographic trends. Pollen and spores allowed reconstruction of floral community and thus characterization of the climate that prevailed on the continent. Foraminifera, recovered from the Lower Cretaceous to the Pleistocene sedimentary rocks, provided information about the bathymetry, showing different marine settings (e.g., coastal, inner neritic, outer neritic, upper bathyal) in different localities. The bryozoan record is restricted to the Cenozoic. Their colonial growth-forms reflect several environmental conditions such as shallow waters with a low rate of sedimentation, hard substrate and moderate or strong current action for the analyzed localities. The study of the Antarctic ecosystems based on the fossil microbiota and their response to the climate and the continental configuration changes, allowed understanding of the composition and dynamics of the polar environments, which have an important role in the Earth climate.

Keywords **pollen-spores, dinoflagellate cysts, foraminifers, bryozoans, palaeoenvironment, Mesozoic–Cenozoic, James Ross Basin, Antarctic Peninsula**

Citation: Amenábar C R, Caramés A, Adamonis S, et al. Mesozoic and Cenozoic microbiotas from eastern Antarctic Peninsula: adaptation to a changing palaeoenvironment. Adv Polar Sci, 2019, 30(3): 165-185, doi: 10.13679/j.advps.2019.0017

---

1 Introduction

Organic and inorganic-walled microfossils are valuable for biostratigraphy, for the study of ancient palaeoenvironments and also for paleoceanographic reconstruction. They can be recovered in large numbers of specimens and diversity from several sedimentary rocks, both marine and continental.

Microbiota recovered from Antarctic sediments constitute an excellent tool for the knowledge of high latitude marine and continental ecosystems that developed

---

[*] Corresponding author, ORCID: 0000-0003-1280-3903, E-mail: amenabar@gl.fcen.uba.ar; cr_amenabar@yahoo.com.ar

from the Mesozoic to Neogene times, along with macrofossils, sedimentological and isotopic data.

In particular, the organic-walled microfossils known as palynomorphs (mostly pollen grains, spores, and dinoflagellate cysts), and the microfossils of inorganic composition, such as foraminifers and bryozoans, found in isolated exposures located in ice-free areas of James Ross Basin, Antarctic Peninsula, helps us to recognize the sedimentary successions, and understand their characteristics and genesis. In this sense, contributions on palynology and micropaleontology supported by good descriptions, illustrations, robust taxonomy, and precise provenance are essential to expand the knowledge of the Southern Hemisphere earth history.

In the last 140 Ma, the Antarctic Peninsula region underwent environmental changes during the final breakup of Gondwana, until its final isolation and location in the South Polar Region. This was accompanied by changes recorded not only in the marine microbiota but also in continental communities. In this respect, dinoflagellate cysts are especially useful in describing the dynamics of Mesozoic and Cenozoic oceans because they are sensitive to water temperature, salinity, depth, productivity and/or nutrient availability at the water surface, so they are also valuable as paleoenvironmental indicators. The same applies to planktonic foraminifera while benthic foraminifera depend on light, the substrate (hard or soft), nutrients and oxygen availability, temperature and salinity. Bryozoans are tightly controlled by substrate, and also by hydrodynamics and sedimentation rate. In contrast, pollen and spores allow reconstruction of coeval vegetation and prevailing climatic conditions in continental areas where parental plants originate. Since each group of microfossils indicates particular environmental parameters, each of them provides different information, and the combination of them all, allow good reconstructions of the past environments.

Therefore, the aim of this contribution is to compile published literature about some microfossil groups (Tables 1–3) to understand how microbiota changed over time, triggered by environmental changes that took place during Mesozoic and Cenozoic times in the James Ross Basin. The selected literature emphasizes those taxa that indicate particular palaeoenvironmental parameters, e.g., bathymetry, substrate, nutrient levels, oxygenation,figu temperature and salinity of waters, or even positions of ancient shorelines and paleoclimate, among other factors.

2 Geological setting

The James Ross Basin (Figure 1a) constitutes one of the most important back-arc basins located in the northeastern sector of the Antarctic Peninsula, between the 63°30' S and 65° S, and 57° W and 58° W (del Valle et al., 1992; Hathway, 2000). It includes more than 6000 m of marine sediments deposited in two complete transgressive-regressive marine cycles from Jurassic to Eocene (Marenssi et al., 2012). These sediments are overlain by diamictites and alkaline volcanic rocks from James Ross Island Volcanic Group, JRIVG (Nelson, 1975).

Mesozoic sediments include the Jurassic Ameghino Formation (Fm.), also known as Nordenskjold Fm. in English literature (?Oxfordian–Berriasian). This formation is the oldest sedimentary unit within the James Ross Island area and crops out at a number of isolated localities on the eastern coast of the Antarctic Peninsula (Whitham and Doyle 1989). On James Ross Island, the Ameghino Fm. (Figure 1b) occurs as small clasts and as large, isolated, allochthonous glide-blocks enclosed within the Cretaceous Gustav Group (Snape, 1992).

The Cretaceous marine sediments are included in the Gustav and Marambio groups (Figures 1a, 1b). The Gustav Group (Aptian to Coniacian) which is up to 2100 m thick comprises the Lagrelius Point, Kotick Point, Whisky Bay and Hidden Lake Fms. It is composed of conglomerates, sandstones, claystones and shales interpreted as deep marine environments (Ineson et al., 1986). The Marambio Group (Santonian–Danian) is represented by Santa Marta, Rabot, Snow Hill Island, Haslum Crags Sandstones, López de Bertodano and Sobral Fms. This group is 3000 m thick and consists of fine-grained highly fossiliferous sandstones and claystones, subordinated conglomerates, and bioclastic shell beds, deposited in a middle shelf to offshore and inner shelf environments (Rinaldi et al., 1978; Olivero et al., 1986; Crame et al., 1991; Pirrie et al., 1997a; Olivero, 2012; Roberts et al., 2014).

The Cenozoic Seymour Island Group (Late Paleocene–?Oligocene) comprises the Cross Valley–Wiman Fm. (Middle to earliest Late Paleocene, Montes et al., 2013), La Meseta Fm. (Late Paleocene to early Middle Eocene, Rinaldi et al., 1978; Marenssi et al., 1998) and the Submeseta Fm. (Middle Eocene to Early Oligocene, Montes et al., 2013). The sediments of this group represent the final filling stage of the James Ross Basin and they were deposited in incised valleys on an emergent marine platform (Marenssi et al., 1998).

For the La Meseta Fm., Sadler (1988) recognized 7 major lithofacies which he named Telm 1–Telm 7, whereas Marenssi et al. (1998) proposed 6 erosionally-based units (allomembers) namely: Valle de las Focas (equivalent to Telm 1), Acantilados I and II (equivalent to Telm 2 and Telm 3 in part), Campamento (equivalent to Telm 3 in part and Telm 4), and *Cucullaea* I and II (equivalent to Telm 5 and Telm 6 in part). The uppermost Eocene/?Oligocene sediments previously considered as the upper unit of the La Meseta Fm. by Sadler (1988) and others, were named Submeseta allomember by Marenssi et al. (1998), and more recently it was defined as a new formation, the Submeseta Formation (Montes et al., 2013). It was divided into three allomembers denominated Submeseta I or Laminado (Telm 6 in part and Telm 7 in

Table 1 Palynological assemblages from the James Ross Basin indicating age, lithostratigraphic unit, locality and references. For the authorship of the taxon names see the references

Age	Unit and locality	Palynomorphs		References
		Marine (dinoflagellate cysts, acritarch, others)	Terrestrial (pollen-spores)	
Late Pliocene–Pleistocene	Diamictite "Cabo Lamb" (sensu Lirio et al., 2007)	Probably indigenous dinoflagellate chorate cysts *Spiniferites ramosus.* Reworked Late Cretaceous, Paleogene and Neogene dinoflagellate cysts. Difficult to recognize indigenous palynomorphs.	Probably indigenous angiosperms: tricolpate pollen grain attributed to the living *Franseria meyeniana*, *Haloragacidites trioratus*. Cryptogam spore *Ceratosporites equalis* (range: Late Cretaceous–Neogene). Reworked Permian, Late Cretaceous, Paleogene, and Neogene pollen-spores. Difficult to recognize indigenous palynomorphs.	Caramés et al. (2008)
Miocene–Pleistocene (ages range between 5.42 Ma and 2.09 Ma)	Diamictite Leal Bluff, Cape Lamb, Vega Is.	Common indigenous microforaminifera linings of the morphotype Trochospiral type I are close related to the Neogene foraminifera *Trochammina* sp. aff. *T. intermedia.* Probably scarce indigenous acritarch *Palaeostomocystis* sp. Reworked Late Cretaceous dinoflagellate cysts. Difficult to recognize indigenous palynomorphs.	Non indigenous terrestrial-derived palynomorphs recovered. Reworked Late Cretaceous pollen-spores.	Concheyro et al. (2014)
	Diamictite Sandwich Bluff, Cape Lamb, Vega Is.	Non indigenous marine palynomorphs identified. Reworked Late Cretaceous dinoflagellate cysts.	Non indigenous terrestrial derived palynomorphs recovered. Reworked Late Cretaceous pollen-spores.	Concheyro et al. (2014)
Late Pliocene	**Cockburn Island Fm.**, Cockburn Is.	Indigenous dinoflagellate chorate cyst *Spiniferites* sp.	No information	Stilwell (2002)
Early Pliocene	**Hobbs Glacier Fm.**, diamictites of Lachman Crags, Forster Cliff, Cascade Cliff, Pecten Spur, Ekelöf Point, Hobbs Glacier, Hamilton Point, Watchtower, Roundel Point, James Ross Is.	Sporadic occurrence of the indigenous dinoflagellate cyst *Bitectatodinium tepikiense* (in Hobbs Glacier diamictite). Abundant *Impletosphaeridium* spp. (dinoflagellate cyst) and *Leiosphaeridia* spp. (acritarch) in most of the diamictites. Reworked Late Cretaceous (e.g., *Isabelidinium pellucidum*, *Odontochitina porifera*, *Nelsoniella tuberculata*) and Eocene–Oligocene dinoflagellate cysts (e.g., *Deflandrea* cf. *heterophlycta*, *Enneadocysta dictyostila*). Difficult to recognize indigenous palynomorphs.	Non indigenous terrestrial derived palynomorphs recovered. Reworked Late Cretaceous pollen-spores.	Salzmann et al. (2011)
Miocene–Pliocene	**Hobbs Glacier Fm.,** diamictite of Ekelöf Point, James Ross Is.	Probably indigenous chorate dinoflagellate cysts: *Spiniferites* and *Operculodinium.* Abundant reworked Late Cretaceous and Paleogene dinoflagellate cysts.	No information	Adamonis et al. (2010)
Miocene (?Late Miocene)	**Hobbs Glacier Fm.** diamictites near Rabot Point, Hamilton Point and Redonda Point, James Ross Is.	Indigenous *Bitectatodinium tepikiense* (early Miocene to the Holocene) and *Spiniferites* spp. Rare chorate dinoflagellate cysts *Lingulodinium* sp. and *Operculodinium* sp.	Indigenous pollen-spores relatively rare, dominance of undifferentiated bisaccate pollen, and no age-diagnostic forms.	Pirrie et al. (1997b)
Eocene/ Oligocene transition	Diamictites that overlie the Submeseta Fm. but are beneath the Weddell Sea Fm. (Pliocene–Pleistocene), Seymour Is.	Mudstones above the diamict contain the Oligocene dinoflagellate cyst species *Chiropteridium lobospinosum* together with low abundances of the Antarctic endemic *Enneadocysta dictyostila* and *Alterbidinium distinctum*, which are characteristic of the Eocene/Oligocene transition, both species disappear in the Early and earliest Oligocene, respectively.	No information	Ivany et al. (2006)
Latest Eocene	**Submeseta Fm.,** uppermost (after Montes et al., 2013; equivalent to Telm 7 of Sadler, 1988), Seymour Is.	Small numbers of typical Eocene dinoflagellate cysts of the Antarctic endemic assemblages as *Vozzhennikovia rotunda*, *V. apertura*, *Senegalinium asymmetricum* and *Spinidinium macmurdoense* are present throughout most of the section but are absent in the upper part. The dinoflagellate *Impletosphaeridium* spp. and the acritarch *Leiosphaeridia* sp., both increase upsection and are the only palynomorphs recorded in that part. Reworked Late Cretaceous to Palaeocene dinoflagellate cysts.	*Nothofagidites* spp. (of *Nothofagus* southern beech) dominated the vegetation in the lowermost section together with some Podocarpaceae (*Podocarpidites* spp.) conifers similar to Valdivian-type forests found today in Patagonia (Argentina and Chile). Immediately before the Eocene/Oligocene transition, terrestrial palynomorphs decrease, while reworked Permian to Palaeocene specimens increase.	Wrenn and Hart (1988); Askin et al. (1991); Cocozza and Clarke (1992); Barnes and Riding (1994); Askin (1997); Douglas et al. (2014); Warny et al. (2018)

Continued

Age	Unit and locality	Palynomorphs		References
		Marine (dinoflagellate cysts, acritarch, others)	Terrestrial (pollen-spores)	
Middle–Late Eocene	**La Meseta Fm.,** (Telm 1–5 of Sadler, 1988), Seymour Is., (Telm 1–2), Cockburn Is.	Antarctic endemic dinoflagellate cyst assemblage: *Deflandrea antarctica*, *Arachnodinium antarcticum*, *Enneadocysta dictyostila*, *Vozzenikovia apertura*, *Enigmadinium cylindrifloriferum.* Cosmopolitan dinoflagellate cysts: *Thalassiphora pelagica*, *Turbiosphaera filosa*, *Spiniferites multibrevis.*	Pollen of Podocarpaceae (*Phyllocladidites*, *Podocarpidites)* and *Nothofagidites* spp. are dominant; pollen of Proteaceae is often abundant but shows a noticeable decline in relative abundance in the upper part of the unit. Other angiosperm pollen includes *Myricipites harrisii* and *Peninsulapollis* spp.	Wrenn and Hart (1988); Askin et al. (1991); Cocozza and Clarke (1992); Barnes and Riding (1994); Askin (1997); Douglas et al. (2014); Concheyro et al. (2016)
Late Paleocene	**Cross Valley Fm.**, Seymour Is.	The co-occurrence of the dinoflagellate cysts *Deflandrea speciosa*, *Alisocysta circumtabulata* and *Palaeoperidinium pyrophorum*, indicate an Early Late Paleocene age for at least part of the Fm.	No information	Wrenn and Hart (1988); Kemp et al. (2014)
Early Paleocene (mostly Danian)	**Sobral Fm,** Seymour Is.	The dinoflagellate age-diagnostic cyst *Apectodinium homomorphum*, characteristic of Late Paleocene strata worldwide, occurs in the uppermost Sobral Fm. *Impagidinium maculatum* is recorded in the top of the Sobral Fm. indicating the latest Paleocene.	Dominance of Podocarpaceae pollen (*Microcachryidites antarcticus*, *Phyllocladidites mawsonii*), less common *Nothofagidites* spp., some Proteaceae species (*Proteacidites parvus*, *Myricipites harrisii* and common Pteridophyte spores.	Kemp et al. (2014); Bowman et al. (2012, 2015)
Latest Maastrichtian/ earliest Danian	**López de Bertodano Fm./Sobral Fm.** (lowermost), Seymour Is., Vega Is.	*Manumiella* spike: Abundance (acme) of the cavate dinoflagellate cyst *Manumiella* (*M. seelandica*, *M. bertodano*, *M. coronata*, *M. seymourensis*, *M. druggii*) immediately prior to the K/Pg boundary. Three acmes of the dinoflagellate cyst *Impletosphaeridum clavus* occur prior the K/Pg boundary. The acme of the dinoflagellate cyst *Senegalinium obscurum* occurs immediately after the K/Pg boundary. In the base of Sobral Fm. occurs the highest abundance of *Trithyrodinium evittii* indicative of Early Danian. Rare specimens of the dinoflagellate cysts *Carpatella cornuta* and *Damassadinium californicum* were observed immediately above an iridium anomaly in Seymour Is.	Dominance of gymnosperm pollen of Podocarpaceae (*Phyllocladidites mawsonii* and *Podocarpidites* spp.). Angiosperm pollen *Nothofagidites* spp. is also abundant. The angiosperm pollen *Proteacidites* spp. and *Peninsulapollis gillii* are recorded. Pteridophyte and Lycophyte spores are also common elements. Freshwater algae are also documented.	Baldoni and Barreda (1986); Dettmann and Thomson (1987); Thorn et al. (2009); Bowman et al. (2012, 2013a, 2013b, 2014, 2015); Kemp et al. (2014)
Middle-Late Campanian–Late Maastrichtian	**Snow Hill Island Fm**., Ekelöf Point and The Naze, James Ross Is.; Cape Lamb, Vega Is.; Humps Is., Sanctuary Cliffs, Snow Hill Is.; Cockburn Is.	Characterized by peridinoid cavate forms of the genus *Isabelidinium* (*I. pellucidum*, *I. cretaceum*), *Chatangiella*, *Nelsoniella (N. aceras*), *Amphidiadema.* Other taxa are: *Trichodinium castanea*, *Phelodinium magnificum*, *Cerodinium diebelli.* Some chorate taxa are: *Impagidinium* sp., *Impletosphaeridium clavus.* The dinoflagellate chorate cyst *Impletosphaeridum clavus* is very abundant in some levels (acme).	Gimnosperm pollen of Podocarpaceae and Araucariaceae (*Podocarpidites* spp., *Microcachryidites antarcticus*, *Phyllocladidites mawsonii*, *Trichotomosulcites subgranulatus*, *Araucariacites australis*). Angiosperm pollen is abundant and highly diversified with abundant *Nothofagidites* spp. and *Peninsulapollis gillii*. Pteridophyte (*Cyatheacidites* sp., *Leptolepidites verrucatus*) and Lycophyte spores (*Perotrilites majus*) are also present.	Dettmann and Thomson (1987); Askin et al. (1991); Crame et al. (1991); Pirrie et al. (1991); Dolding (1992); Smith (1992); Wood and Askin (1992); Barnes and Riding (1994); Pirrie and Riding (1988); di Pasquo and Martin (2013); Amenábar et al. (2014); Caramés et al. (2016)
Latest Santonian–Late Campanian	**Rabot Fm.** (sensu Lirio et al. 1989), Rabot Point, E James Ross Is.	Characterized by peridinoid cavate forms of the genus *Nelsoniella*, *Chatangiella* and *Satyrodinium* and other taxa from the older units (*Odontochitina* spp., *Heterosphaeridium*). *Nelsoniella aceras*, *N. tuberculata* and *Satyrodinium bengalense* indicate an Early–middle Campanian and probable the base of the Late Campanian.	No information	Crame et al. (1991); Sumner (1992); Amenábar and Lirio (2015)

Continued

Age	Unit and locality	Palynomorphs		References
		Marine (dinoflagellate cysts, acritarch, others)	Terrestrial (pollen-spores)	
Middle–Late Eocene	**La Meseta Fm.,** (Telm 1–5 of Sadler, 1988), Seymour Is., (Telm 1–2), Cockburn Is.	Antarctic endemic dinoflagellate cyst assemblage: *Deflandrea antarctica*, *Arachnodinium antarcticum*, *Enneadocysta dictyostila*, *Vozzenikovia apertura*, *Enigmadinium cylindrifloriferum.* Cosmopolitan dinoflagellate cysts: *Thalassiphora pelagica*, *Turbiosphaera filosa*, *Spiniferites multibrevis.*	Pollen of Podocarpaceae (*Phyllocladidites*, *Podocarpidites)* and *Nothofagidites* spp. are dominant; pollen of Proteaceae is often abundant but shows a noticeable decline in relative abundance in the upper part of the unit. Other angiosperm pollen includes *Myricipites harrisii* and *Peninsulapollis* spp.	Wrenn and Hart (1988); Askin et al. (1991); Cocozza and Clarke (1992); Barnes and Riding (1994); Askin (1997); Douglas et al. (2014); Concheyro et al. (2016)
Late Paleocene	**Cross Valley Fm.**, Seymour Is.	The co-occurrence of the dinoflagellate cysts *Deflandrea speciosa*, *Alisocysta circumtabulata* and *Palaeoperidinium pyrophorum*, indicate an Early Late Paleocene age for at least part of the Fm.	No information	Wrenn and Hart (1988); Kemp et al. (2014)
Early Paleocene (mostly Danian)	**Sobral Fm,** Seymour Is.	The dinoflagellate age-diagnostic cyst *Apectodinium homomorphum*, characteristic of Late Paleocene strata worldwide, occurs in the uppermost Sobral Fm. *Impagidinium maculatum* is recorded in the top of the Sobral Fm. indicating the latest Paleocene.	Dominance of Podocarpaceae pollen (*Microcachryidites antarcticus*, *Phyllocladidites mawsonii*), less common *Nothofagidites* spp., some Proteaceae species (*Proteacidites parvus*, *Myricipites harrisii* and common Pteridophyte spores.	Kemp et al. (2014); Bowman et al. (2012, 2015)
Latest Maastrichtian/ earliest Danian	**López de Bertodano Fm./Sobral Fm.** (lowermost), Seymour Is., Vega Is.	*Manumiella* spike: Abundance (acme) of the cavate dinoflagellate cyst *Manumiella* (*M. seelandica*, *M. bertodano*, *M. coronata*, *M. seymourensis*, *M. druggii*) immediately prior to the K/Pg boundary. Three acmes of the dinoflagellate cyst *Impletosphaeridum clavus* occur prior the K/Pg boundary. The acme of the dinoflagellate cyst *Senegalinium obscurum* occurs immediately after the K/Pg boundary. In the base of Sobral Fm. occurs the highest abundance of *Trithyrodinium evittii* indicative of Early Danian. Rare specimens of the dinoflagellate cysts *Carpatella cornuta* and *Damassadinium californicum* were observed immediately above an iridium anomaly in Seymour Is.	Dominance of gymnosperm pollen of Podocarpaceae (*Phyllocladidites mawsonii* and *Podocarpidites* spp.). Angiosperm pollen *Nothofagidites* spp. is also abundant. The angiosperm pollen *Proteacidites* spp. and *Peninsulapollis gillii* are recorded. Pteridophyte and Lycophyte spores are also common elements. Freshwater algae are also documented.	Baldoni and Barreda (1986); Dettmann and Thomson (1987); Thorn et al. (2009); Bowman et al. (2012, 2013a, 2013b, 2014, 2015); Kemp et al. (2014)
Middle-Late Campanian–Late Maastrichtian	**Snow Hill Island Fm.**, Ekelöf Point and The Naze, James Ross Is.; Cape Lamb, Vega Is.; Humps Is., Sanctuary Cliffs, Snow Hill Is.; Cockburn Is.	Characterized by peridinoid cavate forms of the genus *Isabelidinium* (*I. pellucidum*, *I. cretaceum*), *Chatangiella*, *Nelsoniella (N. aceras*), *Amphidiadema.* Other taxa are: *Trichodinium castanea*, *Phelodinium magnificum*, *Cerodinium diebelli.* Some chorate taxa are: *Impagidinium* sp., *Impletosphaeridium clavus.* The dinoflagellate chorate cyst *Impletosphaeridum clavus* is very abundant in some levels (acme).	Gimnosperm pollen of Podocarpaceae and Araucariaceae (*Podocarpidites* spp., *Microcachryidites antarcticus*, *Phyllocladidites mawsonii*, *Trichotomosulcites subgranulatus*, *Araucariacites australis*). Angiosperm pollen is abundant and highly diversified with abundant *Nothofagidites* spp. and *Peninsulapollis gillii*. Pteridophyte (*Cyatheacidites* sp., *Leptolepidites verrucatus*) and Lycophyte spores (*Perotrilites majus*) are also present.	Dettmann and Thomson (1987); Askin et al. (1991); Crame et al. (1991); Pirrie et al. (1991); Dolding (1992); Smith (1992); Wood and Askin (1992); Barnes and Riding (1994); Pirrie and Riding (1988); di Pasquo and Martin (2013); Amenábar et al. (2014); Caramés et al. (2016)
Latest Santonian–Late Campanian	**Rabot Fm.** (sensu Lirio et al. 1989), Rabot Point, E James Ross Is.	Characterized by peridinoid cavate forms of the genus *Nelsoniella*, *Chatangiella* and *Satyrodinium* and other taxa from the older units (*Odontochitina* spp., *Heterosphaeridium*). *Nelsoniella aceras*, *N. tuberculata* and *Satyrodinium bengalense* indicate an Early–middle Campanian and probable the base of the Late Campanian.	No information	Crame et al. (1991); Sumner (1992); Amenábar and Lirio (2015)

Table 2 Foraminiferal assemblages from the James Ross Basin indicating age, lithostratigraphic unit, locality and references

Age	Unit and location	Foraminifers	References
Post Late Pliocene–Pleistocene	**Weddell Sea Fm**., Seymour Is.	Reworked benthic foraminifers in a terrestrial melt-out till (inner morraine deposit). Indeterminated species of the genera *Cyclammina*, *Haplophragmoides*, *Ammobaculites*, *Ammodiscus*, *Textularia*, *Trochammina* and *Cribrostomoides*? probably proceed from Cretaceous and Cenozoic strata of the James Ross Basin, while *Ammoelphidiella antarctica* Conato and Segre along with representatives of the family Cassidulinidae, came from erratic boulders of the Pliocene conglomerate Cockburn Island Fm.	Malagnino et al. (1981); Gaździcki et al. (2004)
Late Pliocene–Early Pleistocene	**Terrapin Fm.**, Fiordo Belén, James Ross Is.	Poorly preserved and low diverse benthic foraminiferal assemblages, with abundant specimens of the family Cassidulinidae and Fursenkoinidae. *Elphidium excavatum* (Terquem), *E. gunteri* Cole, *Cassidulina crassa* d'Orbigny, *Globocassidulina subglobosa* (Brady), *Fursenkoina earlandi* (Parr) and *Cibicides refulgens* de Montfort were reported.	Lirio et al. (2003)
Late Pliocene–Pleistocene (younger than 2.09 Ma)	Cape Lamb Diamictite, Vega Is.	*Globocassidulina biora* (Crespin) and *Cribroelphidium* sp. aff. *E. excavatum* Terquem are dominant, followed by *Cibicides refulgens* de Montfort, *Globocassidulina* sp., *Cassidulinoides parkerianus* (Brady), *Epistominella vitrea* Parker, *Astrononion antarcticum* Parr, *Nonionella bradii* (Chapman), *Astrononium echolsi* Kennett and some accessory species. The foraminifers were interpreted as parautochthonous and coeval with those yielded from the Terrapin Formation, because both units contain the scallop *Adamussium colbecki* (Smith) and the lack of *Ammoelphidiella* sp. nov. and *A. antarctica*.	Caramés and Concheyro (2013)
Miocene–Pleistocene	Leal Bluff diamictite, Vega Is.	Only one specimen of *Dorothia* sp. and one of *Trochammina* sp. aff. *T. intermedia* Rhumbler were recovered. The latter was considered as probably autochthonous because its well preserved inner-organic layer was related to several microforaminiferal linings (Trochospiral, type 1) that are part of the autochthonous palynomorph assemblage recovered from the same sample.	Concheyro et al. (2014)
Indeterm. age (older than 5.42 Ma)	Sandwich Bluff diamictite, Vega Is.	Isolated specimens of *Pullenia jarvisi* Cushman, *Cibicides* sp. and *Gavelinella* sp. They are considered as reworked specimens from underlying rocks. *Pullenia* was reported from the López de Bertodano Fm. and *Gavelinella* is a cosmopolitan genus that commonly occurs in the Cretaceous and dramatically decreases in the Cenozoic.	Concheyro et al. (2014)
Late Pliocene	**Cockburn Island Fm.**, Cockburn Is.	Exclusively calcareous benthic foraminiferal assemblages with *Cassidulina crassa* d'Orbigny, *Globocassidulina subglobosa* (Brady), *Cassidulinoides parkerianus* (Brady), *Cibicides lobatulus* de Montfort and *Ammoelphidiella antarctica* Conato and Segre as the most abundant species.	Holland (1910); Gaździcki and Webb (1996)
Miocene–Pliocene	Ekelöf Point diamictites, James Ross Is.	Diamictites underlying the James Ross Volcanic Group (JRVG) report *Ammoelphidiella antarctica* Conato and Segre, *Pyrgo fornasinii* Chapman and Parr, *Cassidulinoides parkerianus* (Brady), *Epistominella vitrea* Parker, *Cibicides refulgens* de Montfort and *C. lobatulus* (Walker and Jacob).	Adamonis et al. (2010); Concheyro et al. (2011)
Pliocene	**Gage Fm.**, Cape Gage, James Ross Is.	Calcareous foraminifers dominated by *Cibicides lobulatus* (Walker and Jacob), followed by *Cribrononion* sp., *Ammoelphidiella antarctica* Conato and Segre and *Cassidulina crassa/subglobosa. Ammoelphidiella antarctica* indicates a Pliocene age.	Jonkers et al. (2002)
Late Miocene	**Belén Fm.**, Belén Fjord, James Ross Is.	Calcareous assemblages dominated by the benthics *Cassidulina crassa/subglobosa*, followed by *Cassidulinoides parkerianus* (Brady) and *Ammoelphidiella* sp. nov. *Ammoelphidiella* sp. nov. has been highlighted as a stratigraphic usefulness species restricted to the Late Miocene (Jonkers et al., 2002). Four planktonic specimens identified as *Globigerina glutinata* (Egger) and *Globorotalia* sp. were also reported.	Jonkers et al. (2002); Lirio et al. (2003).
Late Miocene	**Hobbs Glacier Fm.**, Hamilton and Rabot Points, James Ross Is.	Glacimarine diamictites of three sections from the area of Hamilton Point yielded the calcareous benthic taxa *Astacolus* sp. aff. *A. crepidularis* (Fichtel and Moll), *Lenticulina* sp. aff. *L. limbosa* (Reuss), *Cassidulinoides parkerianus* (Brady), *Globocassidulina subglobosa* (Brady), *Ammoelphidiella* sp. nov. and *Nonionella bradii* (Chapman), as well as allocthonous agglutinated species. In Rabot Point area were reported dominant *C. parkerianus*, followed by *Ammoelphidiella* sp. nov. and *Cassidulina crassa/subglobosa* with few species of barnacles and rare bivalves. Based on the presence of *Ammoelphidiella* sp. nov. a Late Miocene age was suggested by Jonkers et al. (2002).	Bertels-Psotka et al. (2001); Jonkers et al. (2002); Concheyro et al. (2007)
Late Miocene	**Mendel Fm.**, Ulu Peninsula, James Ross Is.	Only three specimens were recovered from eight samples: *Hoeglundina asanoi* Matsunaga, *Nonionella bradii* (Chapman) and *Globocassidulina* sp. As they were obtained solely from terrestrial glacigenic units of the Mendel Formation they were interpreted as reworked from marine sediments.	Nývlt et al. (2011)
Middle–Late Eocene	**La Meseta Fm.**, Seymour Is., Telm 1 of Sadler (1988) or Valle de las Focas allomember of Marenssi et al. (1998)	Two distinctive benthic foraminiferal assemblages in composition and richness were found in two samples near the base of the sequence. One of them is dominated by ?*Nonionellina* sp., *Nonionella bradyi* (Chapman), *Globocassidulina subglobosa* (Brady) and *Eilohedra vitrea* (Parker), and the other one by *Globocassidulina subglobosa*, *Cribroelphidium* aff. *lauritaense* (Todd and Knicker), *C.* aff. *saginatum* (Finlay), *Guttulina irregularis* (d'Orbigny) and *Lobatula* sp. A third sample, which is also from the lower member, only yielded five poorly preserved specimens, three of which are problematic planktonic specimens. The two *Cribroelphidium* species are known only from the Eocene of New Zealand and Patagonia.	Gaździcki and Majewski (2012)

Continued

Age	Unit and location	Foraminifers	References
Paleocene (mostly Danian)	**Sobral Fm.**, Seymour Is.	Basal unit of the Sobral Formation yielded a foraminiferal assemblage dominated by calcareous tests. The benthic *Buliminella procera* Huber is restricted to this unit and it is the most abundant species. The Danian index fossil *Globastica daubjergensis* (Brönnimann) is the only planktonic species recovered.	Huber (1988)
Late Maastrichtian –Danian	**López de Bertodano Fm.**, SW Seymour Is., NE Snow Hill Is., The Naze–NNE James Ross Is., Cape Lamb–Vega Is.	Most of the Cretaceous sequence yielded wholly agglutinated or agglutinated assemblages with poorly preserved calcareous benthic taxa and few planktonics, and did not register important biotic changes. The benthics are mainly cosmopolitan species, but *Bolivina incrassata* Reuss, *Frondicularia rakauroana* (Finlay) and *Gaudryina healyi* Finlay were the only ones highlighted as benthic species useful for extra-basinal correlations. Most common planktonics are *Herbergella sliteri* Huber (1992) (=*H. monmouthensis* in Huber 1988), *Globigerinoides multispinatus* (Lalicker), *Heterohelix globulosa* (Ehrenberg), *Archaeoglobigerina mateola* Huber (1992) (=*Rugoglobigerina*? sp. 1 Huber 1988) and *R. rugosa* (Plummer). Based on the planktonics that have their highest stratigraphic occurrence from within 1 to 4 m below a glauconitic bed, a Late Campanian–Maastrichtian age was suggested. Higher up, above the glauconitic interval, near the K/Pg boundary, a dramatic faunal turnover occurs. This interval is known as "dissolution facies" due to the disappearance of 71% of the agglutinated species, 64% of the benthic calcareous and 100% of the planktonic species. The overlying stratigraphical intervals contain few poorly preserved agglutinated foraminifers. *Cyclammina* cf. *C. complanata* Chapman, *Alveolophragmium macellarii* Huber and *Hyperammina elongata* Brady, which are also the most common foraminifers on the whole Cretaceous sequence, were considered as solution resistant forms. The cosmopolitan Danian planktonic index *Globastica daubjergensis* (Brönnimann) was recovered 1 m below the López de Bertodano/Sobral Fms. The first and last occurrences of selected taxa were used to define biostratigraphic zones for the James Ross region: The *Gaudryina healyi* assemblage-zone was used to correlate the Cape Lamb (Vega Is.), The Naze (James Ross Is.) and Snow Hill strata (nevertheless, we have to keep in mind that the lowermost Seymour Island beds are currently considered as belonging to the upper levels of Snow Hill Island Fm., thus, this assemblage includes them along with the first 150 m of the López de Bertodano Fm.), the *Hedbergella monmouthensis* Zone, occurs only on Seymour Is. below the dissolution facies, and the *Gaudryina daubjergensis* Zone, occurs only on Seymour Is. above the dissolution facies.	Huber (1988)
Late Campanian and possible Early Maastrichtian	**Snow Hill Island Fm.**, Hamilton Point Mbr, Ekelöf Point, James Ross Is.; Cape Lamb, Vega Is.; Nordenskjöld hut (Refugio Suecia), NE Snow Hill Is.	Ekelöf Costa, Chorrillo Leonardo and Ekelöf Ovest respectively, expose the lower, middle and upper part of the Upper Cretaceous sequence outcropping in the area of the Ekelöf Point. At Ekelöf Costa section the assemblage consists of scarce and low diverse benthic taxa with dominant agglutinated epifaunals Astrorhizaceans (*Batysiphon* spp.) and Spiroplectamminaceans (*Spiroplectammina chicoana* Lalicker), followed by deep infaunals Hormosinaceans (*Reophax globosus* Sliter). Chorrillo Leonardo and Ekelöf Ovest also result dominated by agglutinated, but epifaunal Lituolaceans (*Haplophragmoides* and *Trochamminoides*) predominate, in addition to lower proportions of infaunals Hormosinaceans (*Hormosina*, *Reophax* and *Subreophax*). The planktonic *Globotruncana* sp. was recovered from the highest levels, but its poor preservation prevented any age assignment. The epifaunals are dominant in Chorrillo Leonardo section, whereas the infaunals become progressively abundant upsection and are dominant in the upper part of Ekelöf Ovest section. In the Cape Lamb area an almost monotypic and abundant assemblage of conspicuous and very large agglutinated species was mentioned. Agglutinated undetermined species were also mentioned from Nordenskjöld hut (Refugio Suecia). Finally, some foraminifers recovered from outcrops of Snow Hill Is. and SW of Seymour Is. would belong to highest stratigraphic levels of the Snow Hill Island Formation (see main text). According to Macellari (1988) these levels were deposited in nearshore estuarine environments.	Olivero (1975); Huber (1988); Gennari (1997); Concheyro et al. (1997); Morlotti and Concheyro (1999); Ronchi et al. (2002); Caramés et al. (2016)
Santonian	**Santa Marta Fm.**, Lachman Crags Mbr., NE Brandy Bay, James Ross Is.	Diverse assemblage composed by calcareous and agglutinated tests, with *Gyroidinoides globosus* (Hagenow) emend. Alegret and Thomas and *Gavelinella sandidgei* (Brotzen) as the most abundant taxon. The occurrence of only one specimen of planktonic species *Archaeoglobigerina bosquensis* Pessagno is important from a stratigraphically point of view because its range goes from the Coniacian to the Santonian and its occurrence decreases near the Santonian/Campanian boundary.	Hradecká et al. (2011); Florisbal et al. (2013)
Coniacian–Early Santonian	**Hidden Lake Fm.**, NE Brandy Bay, James Ross Is.	Poor and low diverse assemblage mainly composed of benthic calcareous as *Lenticulina comptoni* (Sowerby), *Lenticulina* sp., *Gavelinella* sp. and *Valvulineria lenticula* (Reuss). On the basis of the planktonics *Marginotruncana schneegansi* (Sigal) and *Archaeoglobigerina bosquensis* Pessagno a Coniacian–Early Santonian age was assigned.	Hradecká et al. (2011)
Late Albian–Turonian	**Whisky Bay Fm.**, NE Brandy Bay, James Ross Is.	Two poorly preserved benthic specimens of the agglutinated *Tritaxia* sp. and the calcareous *Tristix* sp. were found.	Hradecká et al. (2011)
Late Albian	**Kotick Point Fm.**, Tumbledown Cliffs, NW James Ross Is.	Agglutinated and benthic calcareous taxa, dominated by *Ammolagena clavata* (Jones and Parker), *Pullenia coryelli* White and *Trochammina globigeriniformis* (Parker and Jones). According to Webb (1972), the specimen identified as the planktonic ?*Globotruncana contusa* (Cushman) by Mcfadyen (1966) really belong to the family Ataxophragmiidae.	Mcfadyen (1966); Webb (1972)

Notes: The table respects the original taxonomic classification given in each cited work. Nevertheless, according to authoritative classification and catalog of marine names of WoRMS (www.marinespecies.org), the benthic *Cassidulina crassa* d'Orbigny currently is accepted as *Gobocassidulina crassa* (d'Orbigny), *Cassidulina subglobosa* Brady as *Globocassidulina subglobosa* (Brady), *Cassidulinoides parkeriana* (Brady) as *Cassidulinoides parkeriana* (Brady), *Epistominella vitrea* Parker as *Eilohedra vitrea* (Parker), *Cibicides lobatulus* (Walker and Jacob) as *Lobatula lobatula* (Walker and Jacob) and *Lenticulina comptoni* (Sowerby) as *Lenticulina rotulata* (Lamarck). Besides, the planktonic species *Globastica daubjergensis* (Brönnimann) is accepted as *Globoconusa daubjergensis* (Brönnimann) (pforams@mikrotax). And finally, *Nonionella bradyi* (Chapman) has a typographical error and must correspond to *Nonionella bradii* (Chapman).

Table 3 Bryozoan assemblages and type of colonies from the James Ross Basin indicating age, lithostratigraphic unit, locality and references. For the authorship of the taxon names see the references

Age	Unit and locality	Bryozoans	References
Pleistocene	Cape Lamb Diamictite, Vega Is. (interbedded with volcanic rocks of the James Ross Island Volcanic Group, JRIVG)	Colony growth forms: sheet-like colonies encrusting inner and outer surfaces of fragmented shells of the pectinid *Adamussium colbecki* Registered taxa: Crisiid sp. indet., *Ellisina antarctica, Micropora notialis, Hippothoa flagellum* and *Microporella stenoporta.*	Adamonis et al. (2015)
Late Pliocene	**Weddell Sea Fm.**, Marambio (Seymour) Is.	Colony growth forms: only one well-preserved unilaminar, fan-shaped colony, attached to a rocky substratum. Registered taxa: *Escharella* sp. The occurrence of this genus at the Weddell Sea Fm. represents the first record of this genus in Antarctica.	Gazdzicki et al. (2004)
	Cockburn Island Fm. Cockburn Is.	Colony growth forms: encrusting unilamellar colonies and only one species with spheroidal form. Registered taxa: Order Cyclostomata; Order Cheilostomata: families Arachnopusiidae, Inversiulidae, Bryocryptellidae, Smittinidae, Bitectiporidae, Schizoporellidae, Microporellidae, Lacernidae, Celleporidae, Calloporidae, Chaperiidae, Microporidae, Cribilinidae, Romancheinidae	Hennig (1911); Hara and Crame (2010)
?Late Miocene	**Hobbs Glacier Fm.** Marambio (Seymour) Is.	Colony growth forms: well-preserved encrusting and erect bryozoan colonies (unidentified genus and species).	Marenssi et al. (2010)
?Late Miocene	**Hobbs Glacier Fm.**, Hamilton Point, James Ross Is.	Colony growth forms: sheet-like encrusting and erect colonies, being more abundant the last ones. Registered taxa: *Cellarinella stellaepolaris?*, *Microporella* sp., *Polirhabdotos* sp., *Membranicellaria* sp., *Melicerita* sp. and *Hornera* sp. The occurrence of *Cellarinella*, *Polirhabdotos* and *Membranicellaria* extends the stratigraphic range of these taxa into the Miocene.	Concheyro et al. (2007)
?Late Miocene	**Hobbs Glacier Fm.**, Rabot Point, James Ross Is.	Colonies corroded or with mineral cover. In some cases, calcite casts occupy the zooidal chambers. Registered taxa: *Disporella* sp., *Microporella* sp., cf. *Dengordonia,* a celleporoid sp. indet., and an ascophoran sp. indet.	Pirrie et al. (1997b)
Late Eocene/ ?Oligocene	**Submeseta Fm.**, Marambio Is. Telm 7 of Sadler (1988)–Submeseta Allomember of Marenssi et al. (1998)	Locality DPV 13/84 (sensu Hara et al., 2018) Registered taxa ?*Idmidronea* sp., *Celleporaria mesetaensis* and ?*Goodonia* sp.	Hara (2001); Hara et al. (2018)
		Locality ZPAL 3 (sensu Hara, 2001) Registered taxa: five specimens belonging to *Reticresis plicatus,* an erect reticulate colony.	
	Submeseta Fm., Marambio Is. Telm 6 of Sadler (1988)–Submeseta Allomember of Marenssi et al. (1998)	Locality IAA 1/93 (sensu Hara et al., 2018) Registered taxa: *Uharella seymourensis*	
		Locality ZPAL 14 (sensu Hara, 2001) Registered taxa: *Smittina* sp. This is the only site that yields a biostrome of this genus.	
Middle–Late Eocene	**La Meseta Fm.**, Marambio Is. Telm 5 of Sadler (1988)–*Cucullaea* II Allomember of Marenssi et al. (1998)	Colony growth form: colonies encrusting, multiserial, spot- or sheet-like, with autozooids that exhibit umbonuloid frontal shields distinct from those previously recognized. These colonies have been assigned to *Uharella seymourensis* n. gen, n. sp. Registered taxa: *Uharella seymourensis* and colonies of a membraniporimorph anascan and an indeterminate ascophoran.	Taylor et al. (2008); Hara et al. (2018)
		Ungulate Site (sensu Hara et al., 2018) Registered taxa: *Reticresis plicatus, Micropora nordenskjoeldi, Otionellina antárctica, Lunulites marambionis* and *Uharella seymourensis.*	
		Marsupial Site (sensu Hara et al., 2018) Registered taxa: *Lunulites marambionis* and *Uharella seymourensis*	
		Rocket Site (sensu Hara et al., 2018) Registered taxa: *Otionellina eocenica*	
	La Meseta Fm., Marambio Is. Telm 4 of Sadler (1988)–*Cucullaea* I Allomember of Marenssi et al. (1998)	NRM1 Site Registered taxa: *Lunulites marambionis* and *Uharella* seymourensis.	Hara et al. (2018)

Continued

Age	Unit and locality	Bryozoans	References
Middle–Late Eocene	**La Meseta Fm.**, Marambio Is. Telm 2 of Sadler (1988)–Acantilados Allomember of Marenssi et al. (1998)	Locality ZPAL 8 Colony growth form: massive and multilamellar or erect and foliaceous colonies. Registered taxa: *Ceriopora hemisphaerica* and *Rhynchozoon quadratus*	Hara (2001)
		Locality ZPAL 6 Colony growth form: massive, multilamellar, more or less hemispherical colonies. Registered taxa: *Ceriopora hemisphaerica*	
		Near Cape Wiman. The same bryozoan fauna as in Telm 1.	Gazdzicki and Hara (1994)
	Meseta Fm., Marambio Is. Telm 1 of Sadler (1988)–Valle de las Focas Allomember of Marenssi et al. (1998)	Locality ZPAL 12 Less abundant and diverse bryozoan fauna than ZPAL 1 but with a similar taxonomic composition. 68 specimens in total. Colony growth forms: Order Cyclostomata: the dominant colonies are massive, multilamellar cerioporines. Order Cheilostomata: the most represented are lepraliellid colonies. Registered taxa: *Ceriopora hemisphaerica*, *Ceriopora* sp., *Neofungella capitula*, *Reticrescis plicatus*, *Reptomulticava seymourensis*, *Aspidostoma pyriformis*, *Aspidostoma taylori*, *Celleporaria gondwanae*, *Celleporaria mesetaensis*, *Dennisia eocenica*, *Aimulosia lamellosa*, *Osthimosia globosa* and *Rhynchozoon quadratus.*	Hara (2001)
		Locality ZPAL 11 Colony growth forms: low cap-shaped to irregular mushroom-shaped colonies. Registered taxa: *Ceriopora hemisphaerica*, *Celleporaria mesetaensis, Aimulosia lamellosa.*	
		Locality ZPAL 5 Registered taxa: Cyclostomata are more represented than the Cheilostomata. Among the 16 specimens, nine belong to *Crisia* sp. (Family Crisiidae) and six to the Family Cerioporidae. *Crisia* sp., *Ceriopora hemisphaerica*, *Neofungella capitula*, *Reptomulticava seymourensis* and *Aspidostoma multiformis.*	Hara (2001)
		Locality ZPAL 2 Colony growth forms: zoecial molds of unizooidal, bizooidal and branched multiserial internodes of colonies belonging to Cheilostomata. Colony growth forms are membraniporiform/petraliform, cellariform, and cateniceliform, being the first two the dominant colony growth-pattern. Registered taxa: *Beania* cf. *mirabilis*, *Beania* aff. *inermi, Beania* sp., ?*Vasignyella* sp., ?*Malakosaria* sp. and internal moulds of Family Savignyellidae	Hara (2001)
	La Meseta Fm., Marambio Is. Telm 1 of Sadler (1988)–Valle de las Focas Allomember of Marenssi et al. (1998)	Locality ZPAL 1 Colony growth forms: the main morphological types are massive, hemispherical or mushroom-shaped multilamellar colonies, erect branching bilamellar and sheet-like encrusting colonies. Registered taxa: it contains more than 91% of all specimens, yielding the most morphologically diverse and abundant assemblage. The Cyclostomata are more abundant than the Cheilostomata. Within the Order Cyclostomata, the dominant colonies belong to hemispherical or mound-shaped massive cerioporines and reticulate zoaria of *Reticresis* reaching about 52% of all specimens of this site. The most represented groups of the Order Cheilostomata are lepraliellids, buffonellodid, celleporoideans, and aspidostomatids. *Retecrisina antarctica*, *Fasciculipora* sp., *Hornera antarctica*, *Hornera* sp., *Crassohornera* sp., *Calvetia* sp., *Borgella* sp., *Ceriopora hemisphaerica*, *Ceriopora* sp., *Neofungella capitula*, *Reticrescis plicatus*, *Reptomulticava clavaeformis*, *Reptomulticava seymourensis*, *Disporella marambioensis*, *Crassimarginatella* sp., *Aspidostoma coronatum*, *Aspidostoma multiformis*, *Aspidostoma pyriformis*, *Aspidostoma taylori*, *Aspidostoma* sp., *Macropora* sp., *Cellaria* sp. 1, *Cellaria* sp. 2, *Paracellaria* sp., *Melicerita* sp. *?Reptadeonella* sp., *Celleporaria australis*, *Celleporaria gondwanae*, *Celleporaria mesetaensis*, *Celleporaria ovata*, *Celleporaria* sp., *Dennisia eocenica*, *Escharoides* sp., *Cellarinella* sp., *Smittoidea gazdzickii*, *Metroperiella* sp., *Aimulosia lamellosa*, *Osthimosia globosa*, *Osthimosia* sp., *Reteporella* sp., *Rhynchozoon quadratus* and *Macropora antarctica.*	
		Near Cape Wiman Colony growth forms: Cyclostomata represented by free, massive, hemisphaerical colonies and Cheilostomata by free-lying spheroidal multilamellar colonies built of concentric layers of zooids. Registered taxa: *Ceriopora* sp., *Tetrocycloecia* sp., *Membranipora* sp. and *Conopeum* sp.	Gazdzicki and Hara (1994)

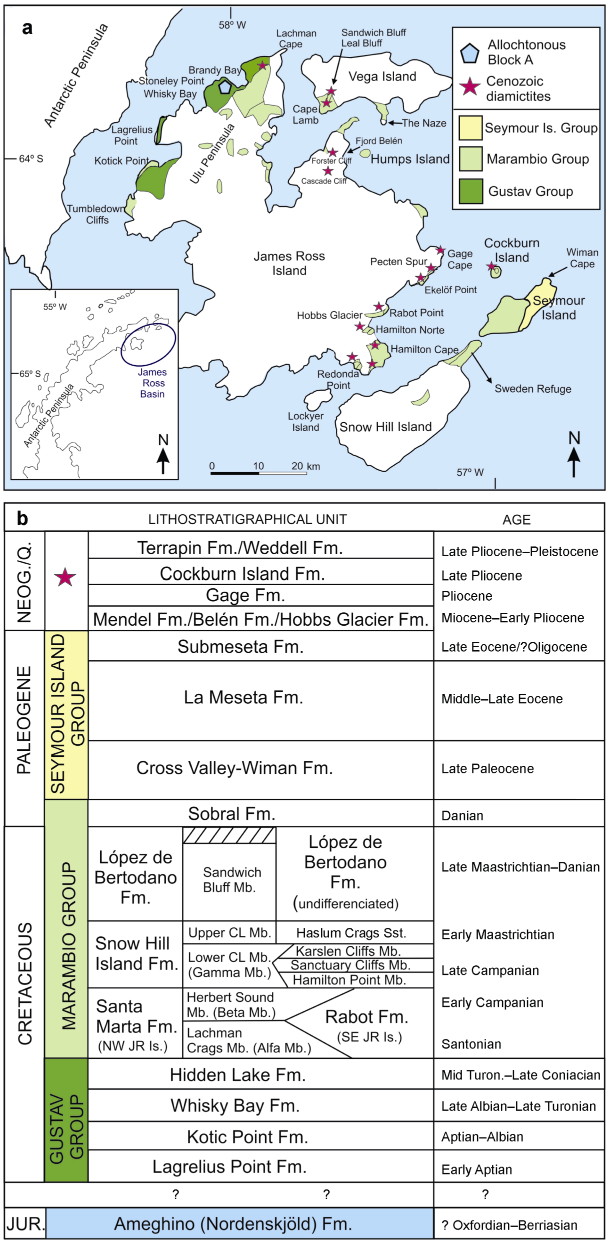

Figure 1 **a**, Location of the James Ross Basin area (after Pirrie et al. (1992); Olivero (2012); Montes et al. (2013)). **b**, Summary of the lithostratigraphy of the James Ross Basin. References: Gustav Group is after Pirrie et al. (1992); Marambio Group is after Crame et al. (1991), Olivero (2012) and Roberts et al. (2014); Seymour Island Group is after Montes et al. (2013), Douglas et al. (2014). Neogene deposits: Mendel Fm. after Nývlt et al. (2011); Hobbs Glacier Fm. after Pirrie et al. (1997b); Belén, Gage and Terrapin Fms. after Lirio et al. (2003); Cockburn Island Fm. after Jonkers (1998); Wedell Fm. after Gaździcki et al. (2004). Abbreviations: Upper CL Mb–Upper Cape Lamb Mb.; Haslum Crags Sst.–Sandstones Alfa, Beta and Gamma Mbs.–Members; NW JR Is.–northwest of the James Ross Island; SE JR Is.–southeast of the James Ross Island.

part), Submeseta II or *Turritella* (Telm 7 in part) and Submeseta III or Superior (upper Telm 7). Even though in many works the ages mentioned above are the ones considered for the La Meseta Fm., Douglas et al. (2014), based on dinoflagellate cyst biostratigraphy, pointed out that the unit was deposited during the Middle to Late Eocene (between 45 Ma and 34 Ma), in contrast with previous Early to Late Eocene age assignments. Therefore, we assumed a Middle to Late Eocene age for the La Meseta Fm. (*sensu* Montes et al., 2013) and an uppermost Eocene/?Oligocene for the Submeseta Fm. (*sensu* Montes et al., 2013).

The Neogene and Quaternary of the James Ross Basin consist of discontinuous outcrops that are represented by Miocene and volcanic and interbedded sedimentary rocks in the James Ross Island Volcanic Group, JRIVG (e.g., Nelson, 1975; Pirrie et al., 1997b). The sedimentary deposits are dominated by diamict and conglomerate with minor sandstones (Smellie et al., 2006). They are included within the Hobbs Glacier Fm. (Pirrie et al., 1997b) and the Cockburn Island Fm., previously known as “Pecten-conglomerate” (Jonkers, 1998). Other fossiliferous diamictites of the James Ross Basin are the Belén and Gage Fms. (Lirio et al., 2003) and the Mendel Fm. (Nývlt et al., 2011). The Quaternary deposits are included within Terrapin Fm. (Lirio et al., 2003) and Weddell Fm. (Gaździcki et al., 2004).

Ice free outcrops show excellent exposures of the Cretaceous Gustav and Marambio Groups and they are concentrated in the James Ross, Vega, Humps, Cockburn, Seymour, and Snow Hill islands. In these islands, Cenozoic diamictites also crop out (Figure 1a). The Seymour Island Group is recognized only in Seymour and Cockburn islands.

The present work focuses on the information provided by the microbiota from the James Ross Basin outcrops. Although cores can also provide further constraints on the Antarctic Peninsula climate changes based on the microbiota, they are beyond the scope of this work. Only microfossils from outcrops will be part of this contribution. Besides, the microbiota considered here consist of palynomorphs, foraminifera and bryozoans. Even though in Antarctic sediments other microfossils are present, such as diatoms, calcareous nannofossils, radiolarians and silicoflagellates; they are excluded from this analysis, since they are out of the scope of the authors’ expertise of the present contribution. The current lithostratigraphical framework of the James Ross Basin is summarized in Figure 1b.

3 Fossil microbiotas from the James Ross Basin

3.1 Palynomorphs

Palynomorphs are very abundant in Jurassic to Cenozoic Antarctic sedimentary rocks; both marine and continental (Table 1).

The Jurassic Ameghino Fm. (Nordenskjöld Fm., in English literature), located in the Antarctic Peninsula, is devoid of recognizable palynomorphs due to local thermal alteration. Nevertheless, the Jurassic palynoflora is known from two sources within James Ross Basin. One of these comes from an allochthonous block on James Ross Island belonging to the Ameghino Fm. that yielded Jurassic index dinoflagellate cyst genera, with typical acavate and proximate forms (a type of cyst based on gross morphology, see Traverse, 2007) indicative of a mid-Tithonian age. Other Jurassic-diagnostic species have been recorded from Lower and Upper Cretaceous sediments due to reworking associated with erosion and transport. The terrestrial-derived palynoflora is only known by the record of a gymnosperm (Family Araucariaceae) pollen grain, of warm and wet climate, which was reworked into the Lower Cretaceous Lagrelius Point and Kotick Point Fms.

The Aptian was a time of widespread marine sedimentation within the Antarctic Peninsula–Scotia Arc–Southern Patagonia region, allowing the comparison of the dinoflagellate cyst assemblages and correlation between these key localities. During the Early Cretaceous (Lagrelius Point, Kotick Point and Whisky Bay Fms.), the dinoflagellate cyst assemblages of James Ross Basin had a wide distribution in southern, high latitude, oceanic regions and they are comparable with the Australian zonal scheme proposed by Helby et al. (1987). Furthermore, Dettmann and Thompson (1987) emphasized the resemblance between Antarctic marine assemblages and southern high-latitude regions, specifying that the James Ross assemblages were referred to the three consecutive dinocyst floras (named as superzones by Helby et al, 1987)—*Muderongia*, *Heterosphaeridium* and *Isabelidinium*—defined by Helby et al. (1987) for the Australian assemblages. The "*Muderongia* dinocyst flora" is rich in gonyaulacoid (= Order Gonyaulacales) taxa and mainly contain the genera *Muderongia* and *Spiniferites*. Dettmann and Thompson (1987) recognized this flora in the Kotick Fm. (Aptian–Albian) and it also seems to be represented in Lagrelius Point Fm. (Early Aptian) based on the taxonomic composition of the assemblage. The "*Heterosphaeridium* dinocyst flora" first occurs during the Middle Albian. It is characterized by gonyaulacoid cysts such as *Cyclonephelium*, *Heterosphaeridium* and *Cribroperidinium,* and the increase of peridinoid (= Order Peridiniales) cysts, especially *Diconodinium*. It was recognized in the Middle Albian–Cenomanian units of James Ross Basin (Kotick Point and Whisky Bay Fms.) by Dettmann and Thompson (1987).

The continental community was relatively uniform across southern Gondwana during the Early Cretaceous times. It consisted of gymnosperms (Family Araucariaceae and Podocarpaceae) and Pteridophyte (ferns), both dominating the forests, with subordinated Lycophyte (club mosses) and Bryophyte (mosses) (Cantrill and Poole, 2012). The vegetation composition is known by the megaflora and the pollen-spore record (Riding et al., 1998; Riding and Crame, 2002, among others). Although the Early Cretaceous Antarctic plant community has the same pollen-spore species as the rest of Gondwana, one of the features that differentiate it, is the low frequency of *Classopollis* spp. For example, the Early Albian assemblages of Falkland Plateau yielded many of the pollen-spore species that have also been documented in James Ross Island. However, in the Falkland Plateau, *Classopollis* (pollen grain of the conifer Cheirolepidaceae) occurs abundantly and other gymnosperm pollen grains (Podocarpaceae, Araucariaceae) are infrequent. This suggests that the climax vegetation of the Falkland Plateau region was predominantly of dry-zone with mangrove cheirolepidacean communities developing, in contrast to the rainforest vegetation of the Antarctic Peninsula. These floral differences may indicate a sharp climatic gradient between the two regions that prevailed during the Early Albian (Dettman and Thompson, 1987). The Early Cretaceous floras of the Antarctic Peninsula gradually became more regional relative to those of the earlier Jurassic to earliest Cretaceous. This was due to the development of new oceanic and atmospheric circulation patterns that generated a thermal gradient in hemispheres, prevailing humid conditions and more precipitation in tropical regions, and expanding cold temperate climates at high latitudes (Cantrill and Poole, 2012).

In the Early Albian of the James Ross Basin (Kotick Fm.), angiosperms (or flowering plants) first appear as pollen records of *Clavatipollenites*, a primitive taxon of a shrubby angiospermous habit (Dettmann and Thomson, 1987). Leaf records of angiosperms occur in the Late Albian (Cantrill and Poole, 2012). By the Coniacian (Hidden Lake Fm.), angiosperms become dominant in the Antarctic floras, developing mixed forests together with conifers.

Returning to the marine realm, towards the Late Cretaceous (Santa Marta, Rabot, Snow Hill Island, López de Bertodano Fms.) other dinoflagellate cyst genera appeared and characterized the marine assemblages. During the Early Santonian–Early Campanian (Santa Marta Fm.) peridinoid cavate forms (*Isabelidinium, Chatangiella*, *Eucladinium, Nelsoniella*, *Satyrodinium*) dominated the dinoflagellate cyst assemblages. This Antarctic assemblage corresponds to the Australian "*Isabelidinium* dinocyst flora" proposed by Helby et al. (1987). It was established by the Santonian–Campanian and ranged up to the Maastrichtian, with a circumpolar distribution in southern high latitudes (Dettmann and Thompson, 1987). It is characterized by abundant and diverse peridinoid dinoflagellate cysts, with intercalary archeopyles (the archeopyle, a taxonomical important feature, is the place at which excystment occurs and the term intercalary refers to the position of the plate that is lost when the cyst splits). In some Campanian–Maastrichtian localities (e.g., Sumner, 1992; Caramés et al., 2016) dinoflagellate cysts and pollen-spores have been used to recognize the position of the coastline and nutrient supply from the continent to the marine environment. The P/G ratio (peridinioid *versus* gonyaulacoid cysts; Versteegh, 1994) and the S/D ratio (sporomorphs or pollen-spores *versus* dinoflagellate cysts; Versteegh, 1994) have been applied in order to infer such palaeoenvironmental conditions.

Going back to the terrestrial community, a clear turnover in pollen taxa is recorded between the Santonian and Campanian. The most dramatic change is the increase in abundance and diversity of the *Nothofagus* group during the Campanian, not only in pollen record (*Nothofagidites*) but also in megafossils such as leaves, wood and reproductive organs (Cantrill and Poole, 2012). The ancestral pollen grains *Nothofagidites endurus* and *N. senectus* were recorded from the Late Campanian–Maastrichtian sediments from the Santa Marta and Snow Hill Island Fms. (e.g., Dolding, 1992; Keating, 1992). By the Campanian-Maastrichtian in Marambio (Seymour) and Vega islands, the genus *Nothofagidites* was well-represented by species belonging to ancestral extinct taxa, and also by others that have affinities with fossil and living species of the *brassi*-type pollen, grouped mainly in the Subgenus *Brassospora*.

By the Maastrichtian, the floras continued to increase in abundance and diversity, with the *Nothofagus* group diversifying further and other angiospermous taxa appearing. Thus, the Early Cretaceous coniferous (Araucariaceae and Podocarpaceae) rainforests were modified during the mid-Campanian by the appearance of *Nothofagus*, which rapidly diversified and became an important component of the vegetation. This changed the aspect of the Late Cretaceous southern temperate forest flora, with podocarps and angiosperms being the main canopy elements of the perhumid, tall open forests, in the Campanian–Maastrichtian.

Towards the end of the Cretaceous and in the Early Cenozoic a gradual cooling occurred (Cantrill and Poole, 2012). This climatic deterioration is evidenced in the dinoflagellate cyst assemblage prior to the K/Pg boundary (López de Bertodano Fm.) that consisted of dominance of the peridinioid genus *Manumiella* spp. (and the closely-related taxon *Isabelidinium*) in the latest Maastrichtian (Thorn et al., 2009). Due to their abundance and diversity within the Late Maastrichtian, the species of *Manumiella* are useful biostratigraphical markers. The genus is typical of relatively near-shore, inner-shelf marine environments. Peaks in abundance (acme) of *Manumiella* recorded within the López de Bertodano Fm. on Marambio (Seymour) Island, may indicate short-term regressions and/or ocean cooling prior to the K/Pg boundary. Similar spikes in abundance of *Manumiella* associated with that boundary have been detected elsewhere (in both Northern and Southern hemispheres), and have been related to mild cooling and regression. The *Manumiella* spike (mostly *Manumiella seelandica*) in the López de Bertodano Fm. would be indicative of a short-term sea-level change prior to the K/Pg, which favored the habitat preferences of that dinoflagellate cyst and reflected a change in trophic levels (probably nutrient-rich surface waters), water temperature or chemistry (Thorn et al., 2009).

Moreover, in the uppermost López de Bertodano Fm. (on Seymour Island), 250 m below the K/Pg boundary, the dinoflagellate cyst *Manumiella seymourensis* occurs together with a great abundance (99% of marine assemblage) of a small spiny palynomorph, which was originally assigned to the acritarch genus *Micrhystridium.* Later it was identified as the chorate dinoflagellate cyst *Impletosphaeridium clavus* by Bowman et al. (2013a, 2013b). In addition to the *I. clavus* acme recognized 250 m below the K/Pg boundary, two extra abundance peaks have been detected within the 1000 m prior to the boundary (Bowman et al., 2013a). The three conspicuous acmes of *I. clavus* have been linked with the presence of Antarctic winter sea-ice during cold episodes in the Maastrichtian, suggesting that temperature could have influenced the blooms of the parental dinoflagellate, and hence the *I. clavus* acmes. This is based on the fact that no other marine palynomorph exhibited an abundance pattern similar to that of *I. clavus* in the uppermost López de Bertodano Fm. Nevertheless, Amenábar et al. (2014) considered that other factors, such as nutrient availability and physico-chemical properties of marine waters, should be taken into account in order to understand the cyst peaks. For example, *I. clavus* is well represented (70% of the marine assemblage) in the Late Campanian–Early Maastrichtian of the Snow Hill Island Fm., in Ekelöf Point (James Ross Island) and in Sanctuary Cliffs (Snow Hill Island) (Amenábar et al., 2014). The *I. clavus* acme in the Upper Campanian–Lower Maastrichtian of the above-mentioned sections would be related to a cold pulse during the Late Cretaceous, but does not necessarily imply the development of sea-ice cover, as was proposed for the uppermost López de Bertodano Fm. Therefore, the Late Cretaceous *Impletosphaeridium* acme recorded in high latitudes, could be a combination of cold and nutrient-rich surface waters that would have favoured the increase in number of that species (and also other peridinoid cysts) and finally its dominance in the palynological assemblages towards to the end of the Cretaceous (Amenábar et al., 2014).

The latest Cretaceous–Early Paleogene vegetation of the James Ross Basin remained relatively stable as regards its overall composition. The floral community consisted of mixed podocarp-southern beech temperate rainforest developed under abundant moisture during the Maastrichtian and earliest Danian (Bowman et al., 2014). Pollen-spore records show that Antarctic Peninsula vegetation suffered little at this time of global biotic disturbance as occurred around the K/Pg boundary elsewhere in the Southern Hemisphere (Bowman et al., 2014).

The Paleogene (~65–35 Ma) was a period of substantial climate change, involving Earth's transition from a greenhouse to an icehouse state; a transition which was not gradual but was characterized by warming intervals, e.g., the Middle Eocene Climatic Optimum (Zachos et al., 2008). The climatic and tectonic changes that occurred during this period strongly influenced the distribution of dinoflagellate cyst assemblages in the Southern Ocean. During the

Paleocene and the Early Eocene (~65–50 Ma) Southern Ocean dinoflagellate cyst assemblages were dominated by cosmopolitan Early Paleogene taxa, while Antarctic-endemic assemblage (composed of species that are restricted to latitudes south of 45°S) were rare (Bijl et al., 2013a, 2013b). A distinct switch from cosmopolitan- dominated to endemic-dominated assemblages occurred around the Early–Middle Eocene boundary (~50 Ma). In the Middle Eocene, Antarctic-endemic taxa began to dominate the dinoflagellate cyst assemblages south of 45°S and prevailed during the Middle–Late Eocene. It is recognized in Middle Eocene units, not only in the La Meseta Fm., but also in the Austral Basin, southern Argentina (González Estebenet et al., 2016). In the latest Eocene, the low-diversity of dinoflagellate cyst assemblages evidence a drop in water temperature and a deterioration of the climate conditions compared to those observed in most of the Eocene. Particularly notable is the increase of reworked dinoflagellate cysts of Cretaceous age in the uppermost Eocene Submeseta Fm. (Warny et al., 2018). Towards the Eocene/Oligocene transition (~34 Ma) profound global climatic and oceanographic changes occurred. These changes were accompanied by a rapid transition from greenhouse to icehouse conditions that were reflected in the Antarctic microbiota, both in marine and continental ecosystems. Close to this transition, the previously ephemeral ice sheets in the Antarctic interior coalesced, becoming relatively stable and permanent. This was influenced by the final opening of the Drake Passage and the initiation of a deep circumpolar current (Cantrill and Poole, 2012). The Antarctic-endemic dinoflagellate cyst assemblage became extinct in the Eocene/Oligocene transition and was replaced by Oligocene cosmopolitan taxa, typically heterotrophic species (Family Protoperidinaceae) with modern analogues living today in sea-ice environments (Houben et al., 2013). This transition is documented by a deposit on Marambio (Seymour) Island, which is the earliest direct evidence for marine-based Cenozoic glaciation on the Antarctic Peninsula (Ivany et al., 2006). The deposit overlies the Submeseta Fm. (or Telm 7 of La Meseta Fm.) and is beneath the Weddell Sea Fm. (Pliocene–Pleistocene). It consists of a diamict with lower and upper pebbly mudstones in between. Mudstones above the diamict yield scarce Oligocene dinoflagellate cyst together with low abundances of the Antarctic-endemic species and other taxa characteristic of Eocene/Oligocene transition that disappear in the Early and earliest Oligocene, respectively. This deposit is similar in age to the one documented by Warny et al. (2018) which is located elsewhere on Marambio (Seymour) Island.

Since the Oligocene, ice sheets and glacial dynamics shaped the Antarctic Peninsula resulting in the reworking of sediments. Glacial processes increasing in areal extent, with further cooling towards the end of the Miocene, strongly reduced the possibilities of finding any indigenous (or *in situ*, *i.e.*, penecontemporaneous with deposition) palynomorphs and so hinder the reconstruction of post-Oligocene marine and continental environments. Geological evidence for Neogene glaciation in the James Ross Basin comes from sporadic terrestrial glacigenic sediments and glaciovolcanic sequences that are exposed on James Ross Island and adjacent areas represented by the Hobbs Glacier and Cockburn Island Fms. together with isolated diamictite deposits (Sandwich and Leal Bluff) on Vega Island. All these diamictites yielded abundant reworked Late Cretaceous dinoflagellate cysts, and some of them also contain scarce Eocene to Oligocene cysts. Some of them (at Cascade Cliffs and Hobbs Glacier localities) also contain rare indigenous dinoflagellate cysts indicative of the Miocene (*Bitectatodinium tepikiense*). Other marine palynomorphs, such as the acritarch genus *Leiosphaeridia* and the dinoflagellate cyst *Impletosphaeridium*, both recorded in most of the diamictites, are considered indigenous elements. *Leiosphaeridia* indicates the presence of sea-ice and near-modern climate conditions during the Late Neogene (Salzmann et al., 2011). The sporadic occurrence of the sub-Arctic to temperate dinoflagellate cyst *Bitectatodinium tepikiense* (in Hobbs Glacier), however, suggests sea surface temperatures might have been substantially warmer during some interglacials.

Considering the Cenozoic floral communities, during the mid-Paleocene mixed forests composed of *Nothofagus*, Podocarpaceae and Proteaceae, comparable to the modern Valdivian rainforests of South America, were developed in the James Ross Basin, at least until the latest Paleocene (Warny et al., 2018). In the Late Eocene, the climate began to cool in relation to declining $p\mathrm{CO}_2$ levels and *Nothofagus* became more dominant in these high southern latitude forests (Cantrill and Poole, 2012). The interpretation of a cooling climate across the Eocene/Oligocene transition is corroborated by the pollen-spore record, which shows a dramatic decrease in diversity, occurrence and abundance of continental palynomorphs. The impoverishment of the palynological assemblage can be seen in the diamictites of Marambio (Seymour) Island, in Hobbs Glacier Fm. (James Ross Island), Cockburn Fm. (Cockburn Island), and diamictites in Vega Island, where sediments are barren of indigenous pollen-spores or they are scarce. From the Oligocene to the Pliocene, extremely adverse conditions for plant growth prevailed in the James Ross Basin, together with a cyclical glacial-interglacial environment. Thus, by the Early Oligocene, the Antarctic flora had become more impoverished, with *Nothofagus* and Podocarpaceae conifers probably dominating the canopy, and with pteridophytes, lycophytes and some bryophytes contributing to the understory. By the Miocene–Pliocene the vegetation was probably more similar to the tundra shrub vegetation of southern South America, supporting local stands of *Nothofagus* and a few other angiosperms and conifer taxa that have been developed in coastal regions (Cantrill and Poole, 2012). Nevertheless, Salzmann et al. (2011), in the unsuccessful efforts to find indigenous pollen-spores in the Early Pliocene diamictites, concluded that, although the lack of indigenous terrestrial-derived palynomorphs cannot be taken as a definite evidence of non-existence of vegetation, the presence of a Pliocene vegetation cover on James Ross Island is improbable, even during warm interglacials. Thus, their assumption supports previous reconstructions of a permanent ice sheet on the Antarctic Peninsula throughout the Late Neogene.

3.2 Foraminifers

Reports of foraminifera from the James Ross Basin are limited to the Cretaceous, Paleogene, Neogene and Quaternary periods (Table 2).

The calcareous and agglutinated benthic foraminifers recovered from Early Cretaceous–Late Cretaceous sediments belonging to Kotick Point, Whisky Bay and Hidden Lake formations are scarce (Mcfadyen, 1966; Webb, 1972; Hradecká et al., 2011). However, it should be noted that few samples of these units were studied. In particular, the low diversity assemblage recovered from a single sample of the Hidden Lake Fm., which appears to be richer and more diverse than the other two units, yielded mainly calcareous and cosmopolitan taxa. According to the planktonic together with the benthic species of the genera *Lenticulina*, *Gavelinella* and *Valvulineria*, the foraminiferal assemblage was interpreted as indicative of outer shelf to an upper bathyal environment with a maximum water-depth of 200–300 m (Hradecká et al., 2011).

The Santonian–Early Campanian Lachman Crags Member of the Santa Marta Fm., which probably corresponds to the Alpha Member of Olivero et al. (1986), was more intensively sampled. It yielded agglutinated and calcareous cosmopolitan taxa, but an important bias in preservation conditions was suggested on the basis that calcareous foraminifera seem restricted to few stratigraphic levels of tuffaceous sandstones cemented by calcium carbonate, while agglutinated foraminifera together with radiolarians occur in sandstone levels in addition to the tuffaceous sandstone (Florisbal et al., 2013). On the basis of the consistent occurrences of *Gyroidinoides globosus,* deep-neritic to upper bathyal paleo-depths were suggested (Hradecká et al., 2011; Florisbal et al., 2013).

The Late Campanian and possibly Early Maastrichtian sediments of the Snow Hill Island Fm., exposed at Ekelöf Point (James Ross Island), yielded agglutinated and calcareous foraminifera. The Ekelöf Costa section, which exposes the lower levels of the unit in the area, yielded low diversity and scarce benthic assemblages mainly composed of cosmopolitan taxa with long stratigraphic ranges and well-known Upper Cretaceous global records (Caramés et al., 2016). A Late Campanian and possibly Maastrichtian age was based on dinoflagellate cysts, and therefore, the section would partially cover the upper part of the NG sequence of Olivero (2012) (Caramés et al., 2016). Outer shelf-upper bathyal environments, in agreement with the sedimentary data and with a record of gonyalaucoid cysts of the genus *Impagidinium* (indicative of outer neritic and oceanic settings), were deduced from the dominance of *Bathysiphon* (epifaunal habitat in tranquil bathyal and abyssal settings), even for the last two fertile samples that yielded high proportion of *Spiroplectammina* (an active deposit feeder that lived at or just below the sediment surface into shelf to marginal marine environments). Although the abundance of *Spiroplectammina*, as well as the S/D and P/G ratios used in palynology, would favour coastal to inner neritic environments interpretation, Caramés et al. (2016) have suggested a deeper environment with a narrow continental shelf which would have allowed the quick transport downslope of the terrestrial palynomorphs, the peridinioid dinoflagellate cysts and the elongate keeled tests of *Spiroplectammina*, and their final accumulation in deeper marine environments.

The Chorrillo Leonardo and Ekelöf Ovest sections characterize the middle and upper part of the Cretaceous sequence exposed in the Ekelöf Point area. Although both sections were first assigned to the Santa Marta Fm., according to the stratigraphy proposed by Olivero (2012), they are part of the Snow Hill Island Fm. Their foraminiferal content was mainly analyzed by Gennari (1997), Concheyro et al. (1997), and Morlotti and Concheyro (1999) to obtain paleoenvironmental information. The species list published by Concheyro et al. (1997) shows assemblages mainly dominated by agglutinated taxa with a mixture of cosmopolitan and indeterminate species. According to the morphological groups recognized in the agglutinated assemblages, Concheyro et al. (1997) inferred outer shelf to slope environments. Based on parallel trends of the generic diversity, the specific diversity and the faunal density along the two sections, Morlotti and Concheyro (1999) interpreted stable bottom environments, good availability of nutrients, bottom water oxygenation and low turbidity. In addition, according to the distribution of morphogroups, with dominant epifaunal (mostly omnivores and opportunists) taxa at the lowest levels and infaunal scavengers increasing upwards and becoming dominant in the upper part of the Ekelöf Ovest section, a generally very low surface water productivity that progressively improved was inferred.

There are a few references to foraminifers recovered from the upper part of the Snow Hill Island Fm. Olivero (1975) described nine indeterminate agglutinated species proceeding from near Nordenskjöld hut (Refugio Suecia), northwest of Snow Hill Island. Ronchi et al. (2002) mention an almost monotypic and abundant assemblage composed of a very large sized, agglutinated endemic, new taxa, recovered from an outcrop at Cape Lamb on Vega Island. Undoubtedly, both assemblages should be studied in more detail. Huber (1988) records *Cyclammina* sp. C. *complanata* Chapman from sediments of the informal *Rotularia* 1 unit (Macellari, 1988). These sediments were originally included in the López de Bertodano Fm. but currently, based on the stratigraphy redefined by Olivero et al. (2007), they are considered the highest stratigraphic levels of the Snow Hill Island Fm. Regarding the other five species found by Huber

(1988) from Snow Hill Island, it is not clear if these species belong to the Snow Hill Island Fm. or the López de Bertodano Fm., due to the unknown location of the samples.

The Upper Cretaceous and Paleocene marine sedimentary sequence of the James Ross Basin is included in the López de Bertodano Fm. The Cretaceous was intensively sampled and studied by Huber (1988) and yielded one of the most abundant foraminiferal faunas recognized in the basin, with assemblages dominated by agglutinated taxa, followed by calcareous benthic and planktonic species. In contrast, the revised Paleocene outcrops were limited to few samples and only a part of them provided foraminifers, mainly calcareous benthic taxa with only a few Danian diagnostic species. As a result of the foraminiferal studies carried out in the López de Bertodano Fm., Huber (1988) found that the biostratigraphic resolution based on foraminifers for the Upper Cretaceous in high-latitude regions had particular problems. Among them, the author highlights the absence of the thermophilic keeled planktonic taxa used in the correlation of low latitude regions; the earlier occurrence of some cosmopolitan planktonic species in the James Ross Basin than in lower latitude regions; and in the James Ross Basin several benthic taxa, such as *Cyclammina* spp., *Frondicularia rakauroana* (Finlay), *Buliminella* spp., *Ceratolamarckina* cf. *C. tuberculata* (Brotzen), *Alabamina westraliensis* (Parr) and *Planispirillina subornata* (Brotzen), predate any other known record in lower latitudes. According to Huber (1988), the recovered foraminiferal fauna is a mixture of cosmopolitan and provincial taxa. The benthic *Cyclammina* cf. *complanata* Chapman, *Gaudryina healyi* Finlay, *Dorothia elongata* Finlay, *Karreriella aegra* Finlay, *Frondicularia rakauroana* (Finlay), *Bulliminella creta* Finlay and *Alabamina creta* (Finlay) were highlighted as austral taxa by Huber (1992). The austral character of planktonic fauna is evidenced by the dominance of rugoglobigerines, hedbergellids and heterohelicids informal groups, which are also present in Tethyan and transitional provinces, along with the endemic austral taxa *Hedbergella sliteri* Huber and *Archaeoglobigerina mateola* Huber (Sliter, 1976; Huber, 1992). In regard to the paleoecologic interpretation, Huber considered that *Cyclammina* cf. *C. complanata* Chapman*, Alveolophragmium macellari* Huber and *Hyperammina elongate* Brady, which are also the most common foraminifera of the Cretaceous sequence of the López de Bertodano Fm., were solution-resistant forms, so he warned about the presence of residual assemblages that should not be applied with confidence for paleo-environmental interpretations. Nevertheless, taking into account high-diversity assemblages that more accurately represent the biocoenosis, Huber (1988) interpreted inner neritic settings for the lower 250 m of the sequence on Seymour Island (the lowest 100 m currently considered as belonging to the Snow Hill Island Fm. and the remaining 150 m to the López de Bertodano Fm.), and outer neritic environments for the upper 950 m of the López de Bertodano Fm.

The presence of foraminifera from the Paleocene Sobral Fm. was exclusively investigated within its informal Unit 1. According to Huber (1988), this unit has the first records of *Lenticulina muensteri* (Roemer) and *Buliminella procera* Huber, as well as some species that have also been recorded in the underlying Cretaceous and Danian stratigraphical levels of the López de Bertodano Fm. The first one is known as an Upper Cretaceous–Danian cosmopolitan species and the second one, which composes as much as 82 % of the total assemblage, has an austral distribution and abundant occurrences from the Maastrichtian to the Eocene in the Austral Basin, south of Argentina (Malumián and Caramés, 1994). Furthermore, as the latest stratigraphic interval of the López de Bertodano Fm., the Sobral Fm. yielded the cosmopolitan Danian index taxon *Globoconusa daubjergensis* (Brönnimann) (= *Globastica daubjergensis* in Huber, 1988). An outer neritic interpretation was based on foraminifers and sedimentary facies. It is important to point out that, unlike the Maastrichtian faunas of the López de Bertodano Fm., the Danian assemblage of the Sobral Fm., as well as the one recovered from the López de Bertodano Fm. above the dissolution facies, are dominated by calcareous benthic foraminifera (see Table 5 in Huber, 1988).

Still within the Paleogene sequence, whose foraminiferal fauna until now was only known on Marambio (Seymour) Island, is the La Meseta Fm. which was described by Gaździcki and Majewski (2012) as a “unique insight into Eocene life in what has become a harsh polar environment”. In the lowermost section (Telm 1) of the La Meseta Fm., near the base of the sequence that cuts into the underlying López de Bertodano Fm., two mainly calcareous benthic assemblages were described by Gaździcki and Majewski (2012). The assemblages were interpreted as typical of shallow marine nearshore conditions on the basis of the almost exclusive presence of hyaline taxa characteristic of inner shelf, marine lagoons and estuarine temperate environments. In particular, one of the assemblages that is composed of numerous *Cribroelphidium* and *Lobatula* suggests shallower and more turbid waters (Gaździcki and Majewski, 2012). Both assemblages yielded the typical post-Paleocene genera *Globocassidulina* and *Cribroelphidium,* and the post-Paleocene species *Globocassidulina subglobossa* (Brady), *Anomalinoides spissiformis* (Cushman and Stainforth)*, Cibicides* aff. *ungerianus* (d’Orbigny) and *Gyroidina zelandica* Finlay. Gaździcki and Majewski (2012) also highlighted the similarities in composition among the La Meseta Fm. and other Eocene foraminiferal assemblages from New Zealand and South America, all of relatively shallow water, with *Cribroelphidium* aff. *lauritaense* (Todd and Kniker) and *C.* aff. *saginatum* (Finlay), similar to the known species of the Eocene of Patagonia and New Zealand, and *Guttulina irregularis* (d’Orbigny) that was found in the Agua Fresca Fm. in Chilean Patagonia.

The succeeding units with foraminifera accumulated during interglacial or glacial periods. The shallow marine sediments of the Cockburn Island Fm. typify sediments accumulated during interglacial warm periods (Gaździcki and Webb, 1996; Jonkers et al., 2002). The other units are considered as glacigenic/glacimarine. Both Cockburn Island Fm. and the other units yielded benthic foraminifers that are autochthonous (those that quickly colonized the sediments), parautochthonous (locally transported in the same environment) or reworked from older units. Once the allochthonous specimens are detected, the post-Early Oligocene foraminiferal assemblages that result are strongly dominated by calcareous taxa and, although each one has diverse population structures, their taxonomic compositions are very similar, including almost all the taxa that are still common in Antarctica. These Neogene–Quaternary sediments containing foraminifers have been deposited on coastal and shelf marine settings. Thus, those shallow-water paleoenvironments would explain the assemblages' similarities. *Ammoelphidiella* has been highlighted as a conspicuous taxon because the genus ranges only until the Pliocene. According to Jonkers et al. (2002), two species have been recorded, *Ammoelphidiella* sp. nov. restricted to the Miocene from Hobbs Glacier and Belén Fms., and *Ammoelphidiella antarctica* Conato and Segre from Gage Fm., Ekelöf Point diamictite and Cockburn Island Fm. Nevertheless, these species should be studied in more detail.

3.3 Bryozoans

Bryozoan assemblages of the James Ross Basin are mainly concentrated in the Cenozoic sediments of the La Meseta Fm. on Marambio (Seymour) Island (Table 3). They also appear in other lithostratigraphic units that consist of diamictite deposits cropping out on James Ross Island. Bryozoans of the orders Cyclostomata and Cheilostomata have been reported from the La Meseta Fm. near Cape Wiman in Telm 1–2 (Gazdzicki and Hara, 1994). The Cyclostomata are represented by the family Ceriopodidae, and the Cheilostomata by the anascan family Membraniporidae, the latter yielding the largest number of specimens.

Other localities on Marambio (Seymour) Island have been studied in order to find fossil bryozoans. Hara (2001) described new assemblages collected at eight localities (ZPAL 1, 5, 11, 12, 6, 8, 14 and 3) from the La Meseta Fm. Among the seven lithofacies defined by Sadler (1988), only Telm 1, 2, 6 and 7 have bryozoans. Telm 1 at ZPAL 1 bears the most diverse and abundant assemblage (43 species and 1048 specimens) while Telm 2, 6 and 7 show a remarkable impoverishment of taxa (4 species and 9 specimens). The assemblage of Telm 2, indicates stressful marine-estuarine conditions, while the one obtained from Telms 6 and 7 has been related to a cooling event that occurred during the Late Eocene. In contrast to the colonies from Telm 1 that are well-preserved, those from Telm 6 and 7 show poor-preservation. The reported bryozoan fauna includes representatives of Cyclostomata and Cheilostomata, the former being more abundant. Hara (2001) described two new genera and 19 new species: *Dennisia eocenica* gen. et sp. n., *Reticrescis plicatus* gen. et sp. n., *Aimulosia lamellosa* sp. n., *Aspidostoma multiformis* sp. n., *Aspidostoma pyriformis* sp. n., *Aspidostoma taylori* sp. n., *Celleporaria australis* sp. n., *Celleporaria gondwanae* sp. n., *Celleporaria mesetaensis* sp. n., *Celleporaria ovata* sp. n., *Ceriopora hemisphaerica* sp. n., *Disporella marambioensis* sp. n., *Neofungella capitula* sp. n., *Osthimosia globosa* sp. n., *Reptomulticava clavaeformis* sp. n., *Reptomulticava seymourensis* sp. n., *Retecrisina antarctica* sp. n., *Rhynchozoon quadratus* sp. n. and *Smittoidea gazdzickii* sp. n. Some genera represent the first record for Antarctica: *Ceriopora*, *Retecrisina*, *Borgella*, *Crassohornera*, *Reptomulticava*, *Metroperiella* and *Celleporaria*. Others, such as *Borgella*, *Neofungella*, *Melicerita*, *Smittina*, *Smittoidea*, *Celleporaria*, *Aimulosia*, *Metroperiella*, *Osthimosia*, *Reteporella* and *Rhynchozoon* represent the earliest fossil record of these genera for Antarctica. Hara (2002) erected a new species of the family Macroporidae, for massive, multilamellar colonies recovered from Telm 1 at ZPAL 1. The new species, *Macropora antarctica,* represents the oldest record of the genus. Hara (2015) described zoecial moulds from Telm 1 at ZPAL 2, belonging to *Beania* cf. *mirabilis*, *Beania* aff. *inermis, Beania* sp., ?*Vasignyella* sp. and ?*Malakosaria* sp., together with some specimens of the Family Savignyellidae. The genus *Beania*, the Family Savignyellidae, Catenicellidae and ?*Malakosaria* present in La Meseta Fm. constitute the earliest fossil record of these taxa in Antarctica.

The bryofauna from Telm 4 (NRM1 Site) and Telm 5 (Rocket Site, Marsupial Site and Ungulate Site) described by Hara et al. (2018) and Taylor et al. (2008) consist of Cyclostomata represented by the family Cerioporidae and the Cheilostomata families such as Microporidae, Lunulitidae, Otionellidae and Brydonellidae. The last ones are represented by new species such as *Micropora nordeskjoeldi*, *Lunulites marambionis*, *Otionellina antarctica*, *Otionellina eocenica* and a new genus and species of an encrusting bryozoan with a different umbonuloid frontal shield, *Uharella seymourensis.* This species along with a biostrome of *Smittina* sp., have been recorded from Telm 6 (Localities ZPAL and IAA 1/93), while Telm 7 (Localities ZPAL 3 and DPV 13/84) yields few specimens of ?*Idmidronea* sp., *Celleporaria mesetaensis*, ?*Goodonia* sp. and *Reticresis plicatus* (Hara, 2001; Hara et al., 2018).

Regarding the association of colonial morphotypes, Hara (2002, 2015) and Gazdzicki and Hara (1994) made inferences about the paleoenvironment of the La Meseta Fm. based on the close relation between the colonial growth forms and various environmental factors (Nelson et al., 1988; Hageman et al., 1998). Many colonial growth forms have been documented, the dominants being the cerioporid and celleporiform types. Less abundant zoarial forms are membraniporiform, adeoniform, reteporiform, retiform, petraliform, catenicelliform and very few cellariform and crissiid colonial types. The occurrence of all these growth forms suggests shallow waters with a low rate of sedimentation, hard substrate and moderate or strong bottom currents for the La Meseta Formation.

The ?Late Miocene Hobbs Glacier Fm., at Rabot Point (James Ross Island) yields bryozoan colonies belonging to Cyclostomata and Cheilostomata represented by *Disporella*, *Microporella*, a species with affinities with *Dengordonia*, an indet. species of a celleporoid and an indet. Cheilostomata species (Pirrie et al., 1997b). In the same unit, but at Hamilton Point (James Ross Island), Concheyro et al. (2007) reported bryozoan encrusting and erect colonies of *Microporella, Melicerira, Hornera, Polirhabdotos, Membranicellaria* and one species showing affinities with *Cellarinella stellaepolari*s, being the last three of the oldest records for the James Ross Basin.

Marenssi et al. (2010) mentioned the presence of bryozoan colonies encrusting a metamorphic rock clast from a diamictite that crops out on Marambio (Seymour) Island. This unit, assigned a Late Miocene age by fossil content and isotopic studies, belongs to the Hobbs Glacier Fm.

The Late Pliocene Cockburn Island Fm. at Cockburn Island, yields encrusting bryozoan faunas represented by at least 14 families of Cheilostomata and Cyclostomata (Hennig, 1911; Hara and Crame, 2010). The Weddell Sea Fm. on Marambio (Seymour) Island is also Late Pliocene in age, and an encrusting unilamellar, fan-shaped colony of *Escharella* has been described by Gazdzicki et al. (2004), being the first record of this genus for Antarctica.

On Vega Island, the Cape Lamb diamictite deposits, dated as Pleistocene, yield a bryozoan assemblage characterized by encrusting colonies that include 4 species of Cheilostomata of the families Calloporidae, Microporidae, Hippothoidae, Microporellidae and 1 Cyclostomata of the family Crisiidae. The presence of *Microporella stenoporta*, *Hippothoa flagellum*, *Ellisina antarctica* and *Micropora notialis* constitute the first record of these bryozoan taxa in Cenozoic diamictites of the Antarctic Peninsula (Adamonis et al., 2015). This fossil fauna resembles the one reported from the Pliocene Cockburn Island Fm. (Hara and Crame, 2010) as well as the recent assemblage registered from Admiralty Bay, King George Island, South Shetlands (Pabis et al., 2014).

4 Final considerations

The comprehensive review presented herein reveals that a considerable number of palynological and micropaleontological studies have been carried out on the James Ross Basin over more than 100 years.

Most researches undertaken in the basin has been palynological studies of sedimentary rocks of Jurassic to Pleistocene age. Studies regarding foraminifera follow those of palynology and comprise records from Lower Cretaceous to Pleistocene sediments. Lastly, bryozoan research is limited to Cenozoic deposits.

The large number of localities that have been studied in order to recover palynomorphs may be due in part to the fact that pollen-spores and dinoflagellate cysts are frequently more abundant in sediments than most other microfossils. Palynomorphs are generally well preserved in all type of sediments with fine silt or clay matrix that is usually appropriate for good preservation of organic-walled microfossils, but highly oxidizing conditions in some continental deposits can cause their destruction. On the other hand, biogenic minerals such as calcium carbonate and silica of the skeletal parts of foraminifers and bryozoans are susceptible to dissolution, leading to a poor representation of their assemblages and consequently underrepresenting the original faunas.

Among the disciplines here summarized, palynology is currently the only one that provided information about the Upper Jurassic of the basin. Therefore, the search for foraminifera should be intensified. Palynological data were essential for reconstructing the Early Cretaceous paleogeography and also allowed the comparison with other southern high latitude regions. The limited information on foraminifera for this period indicates dissolution problems, but the scarcity of studies could also be responsible for the lack of their records. If the search for foraminifera was intensified, the findings could provide relevant paleoenvironmental information, such as in the case of the Lower Albian of the Austral Basin (Patagonia, southern Argentina), where the high planktonic content of foraminifera and calcareous nannoplankton, along with some benthic foraminifera, have revealed high productivity waters and deficient oxygen conditions of the seafloor (Malumián, 1990).

In general, dinoflagellate cysts proved to be good indicators for productivity and/or nutrient availability, surface water temperature or chemistry, the position of ancient shorelines and paleoceanographic trends. Pollen and spores allowed reconstruction of the floral community and thus characterization of the climate that prevailed in the continent. Foraminifera provided information about the bathymetry, showing different marine settings (e.g., coastal, inner neritic, outer shelf, upper bathyal) in different localities. The bryozoan colonial growth forms reflected several environmental factors such as shallow waters with a low rate of sedimentation, hard substrate and a moderate or strong current action on the Antarctic sediments. This proves that interdisciplinary studies have clear advantages. For example, for the Santonian–Campanian of the Lachman Crags Member of the Santa Marta Formation, Florisbal et al. (2013) interpreted a sub-bathyal neritic environment based on the calcareous foraminifera fauna in a section showing a strong bias in the microfossil preservation at some of the levels. The presence of the ostracod *Majungaella* confirmed the shelf environment with warm waters and normal salinity. Whereas, the record of agglutinated foraminifera along with the first radiolarians described for the James Ross Island region at other levels, suggests a Late Cretaceous age. By the same token, an integrated analysis of dinoflagellate cyst and foraminifera conducted in Late Cretaceous strata of Ekelöf Point has produced good results. The dinoflagellate cysts allowed proposing a Late Campanian and possibly Maastrichtian age, while the foraminifera supported outer shelf-upper bathyal environments with a narrow continental shelf.

The microbiota changes triggered by environmental variations that occurred during Mesozoic and Cenozoic times in the James Ross Basin can be synthesized as follows.

From the Late Jurassic up to Late Cretaceous (Early Maastrichtian), the dinoflagellate cyst assemblages had a wide distribution in southern, high latitude, oceanic regions and resemble Australian assemblages. At the end of the Cretaceous (latest Maastrichtian) and in the Early Cenozoic a gradual climatic decline occurred which is evidenced by dinoflagellate cyst assemblages dominated by peridinioid species of the genera *Manumiella* spp.

The Paleocene and Early Eocene dinoflagellate cyst assemblages were dominated by cosmopolitan taxa with a small number of Antarctic-endemic species. But in the Middle Eocene, this trend is reversed, with Antarctic-endemic taxa dominating the assemblages of several circum-Antarctic sites. Their distribution reflects an ocean-circulation pattern characterized by wide clockwise gyres surrounding Antarctica that were disrupted by the opening and deepening of the Tasmanian and Drake passages towards the Eocene/Oligocene transition. In general, during the Paleogene, the assemblages suffered a gradual species turnover, showing a decrease in the number of species since the Oligocene up to the present.

Latest Maastrichtian foraminifera fauna was dominated by abundant agglutinated taxa together with calcareous benthic and planktonic species. During the Cretaceous/Paleogene transition, the high calcareous dissolution prevented evaluation of the changes in the foraminiferal fauna. Upwards, in the Danian, the foraminiferal assemblage only provided scarce calcareous benthic taxa with few age diagnostic species. Eocene foraminifera assemblages, different from all the preceding ones, have a similar composition to those of South America and New Zealand.

During the Eocene, the bryozoan fauna shows a decrease in richness and abundance linked with the advance of cooler conditions that prevailed towards the Late Eocene/Oligocene.

Neogene sediments yielded very scarce indigenous palynomorphs and foraminifera, whereas the fossil bryozoans, although scarce, are autochthonous.

During the Early Cretaceous, the floral community of the James Ross Basin was represented mainly by conifers. The first occurrence of *Nothofagus* in the mid-Campanian, changed the appearance of the southern forest flora, composed equally of gymnosperms and angiosperms. The latest Cretaceous–Early Paleogene vegetation remained relatively stable in overall composition, and by the Oligocene the flora became impoverished but with *Nothofagus* and Podocarpaceae remaining as dominant taxa. The Miocene and Pliocene flora was similar to the tundra shrub vegetation that develops today in southern South America.

Due to the sporadic nature of the outcrops, the study of several disciplines is essential to provide a complete biostratigraphic framework, to reconstruct past environments and to outline paleogeographic schemes. Thus, it would be advisable to conduct an interdisciplinary fieldwork program in order to obtain different microfossils from the same sections and outcrops. This approach will allow a more detailed reconstruction of the marine and continental microbiota of the Mesozoic and Cenozoic of the James Ross Basin.

Acknowledgments The authors are most grateful to the Instituto Antártico Argentino and the Argentinian Air Force for the scientific and logistic support during the Argentine Summer Antarctic Expeditions that enabled sampling for palynological and micropaleontological studies that were incorporated into this contribution. We thank the two reviewers, Juan Perez Panera and Peter Sadler, for their valuable suggestions that allowed us to improve the manuscript. We also thank C. Acosta Hospitaleche (Museo de La Plata, Argentina) and J. N. Gelfo (Museo de La Plata, Argentina) for inviting us to contribute to the Special Issue on “Geology and palaeontology of the James Ross Basin, Antarctic Peninsula”. This paper is contribution number R-287 of the Instituto de Estudios Andinos ‘Don Pablo Groeber’ (IDEAN-CONICET).

References

Adamonis S, Caramés A, Amenábar C R, et al. 2010. Microfósiles calcáreos y palinomorfos de la Diamictita Punta Ekelöf, Mioceno–Plioceno, Isla James Ross, Antártida. La Plata, Argentina: X Congreso Argentino de Paleontología y Bioestratigrafía y VII Congreso Latinoamericano de Paleontología.

Adamonis S, Hara U, Concheyro A. 2015. Late Cenozoic Bryozoa from diamictites of Cape Lamb, Vega Island, Antarctic Peninsula. Pol Polar Res, 36: 325-341.

Amenábar C R, Lirio J M. 2015. Resultados palinológicos preliminares de la Formación Rabot (Cretácico Superior), en Punta Rabot, sudeste de la Isla James Ross, Península Antártica. Montevideo, Uruguay: VIII Congreso Latinoamericano de Ciencia Antártica.

Amenábar C R, Candel S, Guerstein R G. 2014. Small Antarctic Late Cretaceous chorate dinoflagellate cysts: biological and palaeoenvironmental affinities. Palynology, 38: 303-323.

Askin R A. 1997. Eocene–?earliest Oligocene terrestrial palynology of Seymour Island, Antarctica//Ricci C A. The Antarctic region: Geological evolution and processes. Siena (Italy): Terra Antarctica Publication, 993-996.

Askin R A, Elliot D H, Stilwell J D, et al. 1991. Stratigraphy and paleontology of Campanian and Eocene sediments, Cockburn Island, Antarctic Peninsula. J S Am Earth Sci, 4: 99-11.

Baldoni A M, Barreda V. 1986. Estudio palinológico de las Formaciones López de Bertodano y Sobral, isla Vicecomodoro Marambio, Antártida.

Boletín de la IG-USP, Instituto de Geociencias, Universidad de Sao Paulo, 17: 89-98.

Baldoni A M, Medina F. 1989. Fauna y microflora del Cretácico en Bahía Brandy, isla James Ross, Antártida. Serie Científica, Inst. Antártico Chileno, 39: 43-58.

Barnes R P, Riding J B. 1994. Angular unconformity between the López de Bertodano and La Meseta formations (Campanian–Maastrichtian and Eocene), Cockburn Island, northern Antarctic Peninsula. J S Am Earth Sci, 7: 35-44.

Barreda V, Palamarczuk S, Medina P. 1999. Palinología de la Formación Hidden Lake (Coniaciano-Santoniano), Isla James Ross, Antártida. Rev Esp Micropaleontol, 31: 53-72.

Bertels-Psotka A, Concheyro A, Salani F. 2001. Las diamictitas de cabo Hamilton, isla James Ross, Antártida. Caracterización estratigráfica, sus microfósiles. Habana, Cuba: 4° Congreso de Geología y Minería de la Sociedad Cubana de Geología.

Bijl P K, Sluijs A, Brinkhuis H. 2013a. A magneto-and chemostratigraphically calibrated dinoflagellate cyst zonation of the early Palaeogene South Pacific Ocean. Earth-Sci Rev, 124: 1-31.

Bijl P K, Bendle J A P, Bohaty S M, et al. 2013b. Eocene cooling linked to early flow across the Tasmanian Gateway. PNAS, 110: 9645-9650.

Bowman V C, Francis J, Askin R, et al. 2014. Latest Cretaceous–earliest Paleogene vegetation and climate change at the high southern latitudes: palynological evidence from Seymour Island, Antarctic Peninsula. Palaeogeogr Palaeoclimatol Palaeoecol, 408: 26-47.

Bowman V C, Francis J E, Riding J B. 2013a. Late Cretaceous winter sea ice in Antarctica? Geology, 41: 1227-1230.

Bowman V C, Francis J E, Riding J B, et al. 2012. A latest Cretaceous to earliest Paleogene dinoflagellate cyst zonation from Antarctica, and implications for phytoprovincialism in the high southern latitudes. Rev Palaeobot Palyno, 171: 40-56.

Bowman V C, Ineson J, Riding J B, et al. 2015. The Paleocene of Antarctica: Dinoflagellate cyst biostratigraphy, chronostratigraphy and implications for the palaeo-Pacific margin of Gondwana. Gondwana Res, 38: 132-148.

Bowman V C, Riding J B, Francis J E, et al. 2013b. The taxonomy and palaeobiogeography of small chorate dinoflagellate cysts from the Late Cretaceous to Quaternary of Antarctica. Palynology, 37: 151-169.

Cantrill D, Poole I. 2012. The vegetation of Antarctica through geological time. Cambridge: Cambridge University Press.

Caramés A, Amenábar C R, Concheyro A. 2016. Upper Cretaceous foraminifera and palynomorphs from Ekelöf Coast section, Ekelöf Point, eastern James Ross Island, Antarctic Peninsula. Ameghiniana, 53: 333-357.

Caramés A, Amenábar C R, Di Pasquo M, et al. 2008. Foraminíferos y palinomorfos de la Diamictita Cabo Lamb, Plioceno Superior, Isla Vega, Península Antártica. San Salvador de Jujuy, Argentina: 17º Congreso Geológico Argentino.

Caramés A, Concheyro A. 2013. Late Cenozoic Foraminifera from diamictites of Cape Lamb, Vega Island, Antarctic Peninsula. Ameghiniana, 50: 114-135.

Cocozza C D, Clarke C M. 1992. Eocene microplankton from La Meseta Formation, northern Seymour Island. Antarc Sci, 4(3): 355-362.

Concheyro A, Amenábar C R, Santillana S, et al. 2016. Primer registro de nanofósiles calcáreos en la Formación La Meseta (Eoceno medio), Isla Marambio, Antártida. General Roca, Argentina: 11º Congreso de la Asociación Paleontológica Argentina.

Concheyro A, Caramés A, Amenabar C R, et al. 2014. Nannofossils, foraminifera and microforaminiferal linings in the Cenozoic diamictites of Cape Lamb, Vega Island, Antarctica. Pol Polar Res, 35: 1-26.

Concheyro A, Gennari F, Robles Hurtado G, et al. 1997. Microfósiles del Cretácico Superior de Punta Ekelöf, Isla James Ross, Antártida. Buenos Aires, Argentina: 4°Jornadas sobre Investigaciones Antárticas.

Concheyro A, Lirio J M, Amenábar C R, et al. 2011. Geología de la Punta Ekelöf, Isla James Ross, Península Antártica. Neuquén, Argentina: XVIII Congreso Geológico Argentino, S8 Geología, Ambientes y Recursos Naturales de la Antártida.

Concheyro A, Salani F, Adamonis S, et al. 2007. Los depósitos diamictíticos cenozoicos de la Cuenca James Ross, Antártida: una síntesis estratigráfica y nuevos hallazgos paleontológicos. Rev Asoc Geol Argent, 62: 568-585.

Crame J A, Pirrie D, Riding J B, et al. 1991. Campanian–Maastrichtian (Cretaceous) stratigraphy of the James Ross Island area, Antarctica. J Geol Soc Lond, 148: 1125-1140.

del Valle R A, Elliot D H, Thomson M R A. 1992. Sedimentary basins on the east flank of the Antarctic Peninsula: proposed nomenclature. Antarc Sci, 4: 477-478.

Dettmann M E, Thomson M R A. 1987. Cretaceous palynomorphs from the James Ross Island area, Antarctica–a pilot study. Brit Antarct Surv B, 77: 13-59.

di Pasquo M, Martin J E. 2013. Palynoassemblages associated with a theropod dinosaur from the Snow Hill Island Formation (Lower Maastrichtian) at the Naze, James Ross Island, Antarctica. Cret Res, 45: 135-154.

Dolding P J D. 1992. Palynology of the Marambio Group (Upper Cretaceous) of northern Humps Island. Antarc Sci, 4: 311-326.

Douglas P M J, Affek H P, Ivany L C, et al. 2014. Pronounced zonal heterogeneity in Eocene southern high-latitude sea surface temperatures. PNAS, 111(18): 6582-6587.

Florisbal L S, Kochhann K G D, Baecker-Fauth S, et al. 2013. Benthic foraminifera, ostracods and radiolarians from the Lachman Crags Member (Santa Marta Formation), Upper Santonian–Lower Campanian (Upper Cretaceous) of James Ross Island, Antarctica. Rev Bras Paleontolog, 16: 181-196.

Gaździcki A, Hara U. 1994. Multilamellar bryozoan colonies from the Eocene La Meseta Formation of Seymour Island, Antarctica: a preliminary account//Birkenmajer K. Geological results of the Polish Antarctic Expeditions, Part X. Studia Geologica Polonica, 104: 105-116.

Gaździcki A, Majewski W. 2012. Foraminifera from the Eocene La Meseta Formation of Isla Marambio (Seymour Island), Antarctic Peninsula. Antarc Sci, 24: 408-416.

Gaździcki A, Tatur A, Hara U, et al. 2004. The Weddell Sea Formation: post-Late Pliocene terrestrial glacial deposits on Seymour Island, Antarctic Peninsula. Pol Polar Res, 25: 189-204.

Gaździcki A, Webb P N. 1996. Foraminifera from the *Pecten* Conglomerate (Pliocene) of Cockburn Island, Antarctic Peninsula. Palaeontologia Polonica, 55: 147-174.

Gennari F. 1997. I foraminiferi agglutinati delle sezioni di Chorrillo Leonardo e di Ekeloff Ovest (Isola di James Ross, Antartide). Università degli Studi di Parma, Facoltá di Scienze Matematiche, Fisiche e Naturali, Corso di Laurea in Scienze Geologiche.

González Estebenet M S, Guerstein G R, Rodríguez Raising M E, et al. 2016.

Dinoflagellate cyst zonation for the middle to upper Eocene in the Austral Basin, southwestern Atlantic Ocean: implications for regional and global correlation. Geol Mag, 1-15.

Hageman S J, Bock P E, Bone Y, et al. 1998. Bryozoan growth habits: classification and analysis. J Paleontol, 72: 418-436.

Hara U. 2001. Bryozoa from the Eocene of Seymour Island, Antarctic Peninsula//Gaździcki A. Palaeontological results of the Polish Antarctic Expeditions, Part III. Palaeontologia Polonica, 60: 33-156.

Hara U. 2002. A new macroporid bryozoan from Eocene of Seymour Island, Antarctic Peninsula. Pol Polar Res, 23: 213-225.

Hara U. 2015. Bryozoan internal moulds from the La Meseta Formation (Eocene) of Seymour Island, Antarctic Peninsula. Pol Polar Res, 36: 25-49.

Hara U, Crame J A. 2010. Late Cenozoic bryozoans of the Cockburn Island Formation, Cockburn Island, West Antarctica. Oslo, Norway: International Polar Year, Oslo Science Conference.

Hara U, Mörs T, Hagström J, et al. 2018. Eocene bryozoan assemblages from the La Meseta Formation of Seymour Island, Antarctica. Geol Q, 62: 705-728.

Hathway B. 2000. Continental rift to back-arc basin: Jurassic–Cretaceous Stratigraphical and structural evolution of the Larsen Basin, Antarctic Peninsula. J Geol Soc, London, 157: 417-432.

Helby R, Morgan N, Partridge D. 1987. A palynological zonation of the Australian Mesozoic//Jell P A. Studies in Australian Mesozoic palynology. Australas Palaeontol Mem, 4: 1-94.

Hennig A. 1911. Le conglomérat Pleistocène à Pecten de l'île Cockburn. Wissenschaftliche Ergebnisse der Schwedischen Südpolar−Expedition, 1901–1903, Geologie und Paläontologie, 3: 1-73.

Holland R. 1910. The fossil foraminifera: Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition 1901–1903, Geologie und Paläontologie, 3: 1-12.

Houben A J, Bijl P K, Pross J, et al. 2013. Reorganization of Southern Ocean plankton ecosystem at the onset of Antarctic glaciation. Science, 340: 341-344.

Hradecká L, Vodrážka R, Nývlt D. 2011. Foraminifera from the Upper Cretaceous of northern James Ross Island (Antarctica): a preliminary report. Czech Polar Rep, 1: 88-95.

Huber B T. 1988. Upper Campanian–Paleocene foraminifera from the James Ross Island region, Antarctic Peninsula. Geol Soc Am Mem, 169: 163-252.

Huber B T. 1992. Paleobiology of Campanian–Maastrichtian foraminifera in the southern high latitudes. Palaeogeogr Palaeoclimatol Palaeoecol, 92: 325-360.

Ineson J R, Crame J A, Thomson M R A. 1986. Lithostratigraphy of the Cretaceous strata of west James Ross Island. Cret Res, 7: 141-159.

Ivany L C, Van Simaeys S, Domack E W, et al. 2006. Evidence for an earliest Oligocene ice sheet on the Antarctic Peninsula. Geology, 34: 377-380.

Jonkers H A. 1998. The Cockburn Island Formation, Late Pliocene interglacial sedimentation in the James Ross Basin: northern Antarctic Peninsula. Newsl Stratigr, 6(2/3): 63-76.

Jonkers H A, Lirio J M, Del Valle R A, et al. 2002. Age and depositional environment of the Miocene–Pliocene glaciomarine deposits, James Ross Island, Antarctica. Geol Mag, 139: 577-594.

Keating J M. 1992. Palynology of the Lachman Crags Member, Santa Marta Formation (Upper Cretaceous) of north-west James Ross Island. Antarc Sci, 4: 293-304.

Keating J M, Spencer-Jones M, Newham S. 1992. The stratigraphical palynology of the Kotick Point and Whisky Bay Formation, Gustav Group Cretaceous, James Ross Island. Antarc Sci, 4: 279-292.

Kemp D B, Stuart A, Robinson J, et al. 2014. A cool temperate climate on the Antarctic Peninsula through the latest Cretaceous to early Paleogene. Geology, 42: 583-586.

Lirio J M, Núñez H J, Bertels-Psotka A, et al. 2003. Diamictos fosilíferos (Mioceno–Pleistoceno): Formaciones Belén, Gage y Terrapin en la isla James Ross, Antártida. Rev Asoc Geol Argent, 58: 298-310.

Macellari C E. 1988. Stratigraphy, sedimentology and paleoecology of Upper Cretaceous/Paleocene shelf-deltaic sediments of Seymour Island//Feldman R M, Woodburne M O. Geology and paleontology of Seymour Island, Antarctic Peninsula. Geol Soc Am Mem, 169: 25-53.

Macfadyen W A. 1966. Foraminifera from the Upper Cretaceous of James Ross Island. Brit Antarct Surv B, 8: 75-87.

Malagnino E, Olivero E, Rinaldi C A, et al. 1981. Aspectos geomorfológicos de la isla Vicecomodoro Marambio, Antártida. San Luis, Argentina: 8° Congreso Geológico Argentino.

Malumián N. 1990. Foraminíferos bentónicos del Cretácico de cuenca Austral, Argentina//Volkheimer W. Bioestratigrafía de los Sistemas Regionales del Jurásico y Cretácico de América del Sur, 429-495.

Malumián N, Caramés A. 1994. El Daniano marino de Patagonia (Argentina): Paleobiogeografía de los foraminíferos bentónicos. Rev Asoc Geol Argent, 48: 103.

Marenssi S A, Casadio S, Santillana S N. 2010. Record of Late Miocene glacial deposition, on Isla Marambio (Seymour Island), Antarctic Peninsula. Antarc Sci, 12: 193-198.

Marenssi S A, Santillana S, Bauer M. 2012. Estratigrafía, petrografía sedimentaria y procedencia de las formaciones Sobral y Cross Valley (Paleoceno), isla Marambio (Seymour), Antártica. Andean Geol, 39(1): 67-91.

Marenssi S A, Santillana S, Rinaldi C. 1998. Stratigraphy of La Meseta Formation (Eocene), Marambio Island, Antarctica//Casadío S. Paleógeno de América del Sur y de la Península Antártica. Revista de la Asociación Paleontológica Argentina, Publicación Especial, 5: 137-146.

Montes M, Nozal F, Santillana S, et al. 2013. Mapa Geológico de la Isla Marambio (Seymour); escala 1:20.000. Serie Cartográfica Geocientífica Antártica. Con texto complementario. Madrid-Instituto Geológico y Minero de España; Buenos Aires-Instituto Antártico Argentino.

Morlotti E, Concheyro A. 1999. Paleoecological observations on the Upper Cretaceous benthic foraminifera assemblages of Punta Ekelöf, James Ross Island, Antarctica. Campus de Rio Claro, Brasil: 5° Simpósio sobre o Cretáceo de Brasil.

Nelson C S, Hyden F M, Keane S L, et al. 1988. Application of bryozoans zoarial growth-form studies in facies analysis of non-tropical carbonate deposits in New Zealand. Sed Geol, 60: 301-322.

Nelson P H H. 1975. The James Ross Island Volcanic Group of north-east Graham Land. Brit Antarct Surv Scientific Reports, 54: 1-62.

Nývlt D, Košler J, Mlčoch B, et al. 2011. The Mendel Formation: Evidence for Late Miocene climatic cyclicity at the northern tip of the Antarctic Peninsula. Palaeogeogr Palaeoclimatol Palaeoecol, 299: 363-384.

Olivero E B. 1975. Perfil geológico, descripción de la fauna de amonites y geomorfología del extremo NE de las islas Cerro Nevado, Grupo de Islas James Ross, sector Antártico Argentino. TFL, Buenos Aires: Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires.

Olivero E B. 2012. Sedimentary cycles, ammonite diversity and paleoenvironmental changes in the Upper Cretaceous Marambio Group, Antarctica. Cret Res, 34: 348-366.

Olivero E B, Palamarczuk S. 1987. Amonites y dinoflagelados Cenomanianos de la isla James Ross, Antártida. Ameghiniana, 24: 35-49.

Olivero E B, Ponce J J, Marsicano C A. 2007. Depositional settings of the basal López de Bertodano Formation, Maastrichtian, Antarctica. Revista de la Asociación Geológica Argentina, 62: 521-529.

Olivero E B, Scasso R A, Rinaldi C A. 1986. Revisión del Grupo Marambio en la Isla James Ross, Antártida. Contrib Inst Antárt Argent, 331: 1-29.

Pabis K, Hara U, Presler P, et al. 2014. Structure of bryozoan communities in an Antarctic glacial fjord (Admiralty Bay, South Shetlands). Polar Biol, 37: 737-751.

Pirrie D, Crame J, Riding J B. 1991. Late Cretaceous stratigraphy and sedimentology of Cape Lamb, Vega Island, Antarctica. Cret Res, 12: 227-258.

Pirrie D, Crame J, Lomas S A, et al. 1997a. Late Cretaceous stratigraphy of the Admiralty Sound region, James Ross Basin, Antarctica. Cret Res, 18: 109-137.

Pirrie D, Crame J A, Riding J B, et al. 1997b. Miocene glaciomarine sedimentation in the northern Antarctic Peninsula region: the stratigraphy and sedimentology of the Hobbs Glacier Formation, James Ross Island. Geol Mag, 134: 745-762.

Pirrie D, Riding J B. 1988. Sedimentology, palynology and structure of Humps Island, northern Antarctic Peninsula. Brit Antarct Surv B, 80: 1-19.

Riding J B, Crame J A, 2002. Aptian to Coniacian (Early–Late Cretaceous) palynostratigraphy of the Gustav Group, James Ross Basin, Antarctica. Cret Res, 23: 739-760.

Riding, J B, Crame J A, Dettmann M E, et al. 1998. The age of the base of the Gustav Group in the James Ross Basin, Antarctica. Cret Res, 19: 87-105.

Riding J B, Keating J M, Snape M G, et al. 1992. Preliminary Jurassic and Cretaceous dinoflagellate cyst stratigraphy of the James Ross Island area, Antarctic Peninsula. Newsl Stratigr, 26: 19-39.

Rinaldi C A, Massabie A, Morelli J, et al. 1978. Geología de la isla Vicecomodoro Marambio, Antártica. Contrib Inst Antárt Argent, 217: 1-37.

Roberts E M, Lamanna M C, Clarke J A, et al. 2014. Stratigraphy and vertebrate paleoecology of Upper Cretaceous–?lowest Paleogene strata on Vega Island, Antarctica. Palaeogeogr Palaeoclimatol Palaeoecol, 402: 55-72.

Ronchi D, Concheyro A, Bagnola M. 2002. Foraminíferos aglutinados del Cretácico Superior de Cabo Lamb, Isla Vega, Antártida. Corrientes, Argentina: VIII Congreso Argentino de Paleontología y Bioestratigrafía.

Sadler P. 1988. Geometry and stratification of uppermost Cretaceous and Paleogene units of Seymour Island, northern Antarctic Peninsula// Feldmann R M, Woodburne M O. Geology and paleontology of Seymour Island, Antarctic Peninsula. Geol Soc Am Mem, 169: 303-320.

Salzmann U, James B, Riding J B, et al. 2011. How likely was a green Antarctic Peninsula during warm Pliocene interglacials? Palaeogeogr Palaeoclimatol Palaeoecol, 309: 73-82.

Sliter W V. 1976. Cretaceous foraminifers from the southwestern Atlantic Ocean, Leg 36, Deep Sea Drilling Project//Wise S W. Initial reports of the Deep Sea Drilling Project 36, 519-573.

Smellie J L, Mcarthur J M, Mcintosh W C, et al. 2006. Late Neogene interglacial events in the James Ross Island region, northern Antarctic Peninsula, dated by Ar/Ar and Sr isotope stratigraphy. Palaeogeogr Palaeoclimatol Palaeoecol, 242: 169-187.

Smith S W. 1992. Microplankton from the Cape Lamb Member, López de Bertodano Formation (Upper Cretaceous), Cape Lamb, Vega Island. Antarc Sci, 4: 337-353.

Snape M G. 1992. Dinoflagellate cysts from an allochthonous block of Nördenskjold Formation (Upper Jurassic), north-west James Ross Island. Antarc Sci, 4: 267-278.

Stilwell J D. 2002. Geological exploration of Cockburn Island, Antarctic Peninsula. Pol Polar Res, 23: 47-73.

Sumner P W. 1992. Dinoflagellate cysts from the Rabot Member (Santa Marta Formation) of eastern James Ross Island. Antarc Sci, 4: 305-310.

Taylor P, Casadio S, Gordon D. 2008. A rare form of frontal shield development in the new cheilostome bryozoan genus Uharella from the Eocene of Antarctica. Paläont Z, 82: 262-268.

Thorn V C, Riding J B, Francis J E, 2009. The Late Cretaceous dinoflagellate cyst Manumiella-biostratigraphy, systematics, and palaeoecological signals in Antarctica. Rev Palaeobot Palynol, 156: 436-448.

Traverse A. 2007. Paleopalynology. Second Edition. New York: Springer.

Versteegh G J M. 1994. Recognition of cyclic and non-cyclic environmental changes in the Mediterranean Pliocene: a palynological approach. Mar Micropaleontol, 23: 147-183.

Warny C S, Kymes M, Askin R, et al. 2018. Terrestrial and marine floral response to latest Eocene and Oligocene events on the Antarctic Peninsula. Palynology, 43(1): 4-21.

Webb P N. 1972. Comments on the reported occurrence of ?*Globotruncana contusa* (Cushman) from the Upper Cretaceous of James Ross Island, Grahamland, Antarctica. New Zeal J Geol Geop, 15: 183-18.

Whitham A G, Doyle P. 1989. Stratigraphy of the Upper Jurassic–Lower Cretaceous Nordenskjold Formation of eastern Graham Land, Antartica. J S Am Earth Sci, 2: 371-384.

Wood S A, Askin R A. 1992. Dinoflagellate cysts from the Marambio Group (Upper Cretaceous) of Humps Island. Antarc Sci, 4: 327-336.

Wrenn J H, Hart G F. 1988. Paleogene dinoflagellate cyst biostratigraphy of Seymour Island, Antarctica. Geol Soc Am Mem, 169: 321-447.

Zachos J C, Dickens G R, Zeebe R E. 2008. An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. Nature, 451: 279-283.