Antarctic Science 24(4), 408–416 (2012) © Antarctic Science Ltd 2012 doi:10.1017/S095410201200020X

Foraminifera from the Eocene La Meseta Formation of Isla Marambio (Seymour Island), Antarctic Peninsula

ANDRZEJ GAŹDZICKI and WOJCIECH MAJEWSKI*

Institute of Paleobiology, Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland
**Corresponding author: wmaj@twarda.pan.pl*

Abstract: Benthic foraminiferal assemblages are described for the first time from the early Eocene of West Antarctica. They come from the lower member (Telm1) of the La Meseta Formation of Isla Marambio (Seymour Island). Two distinctive assemblages, dominated by *Nonionellina*, *Nonionella*, *Globocassidulina*, and *Eilohedra*, as well as by *Globocassidulina*, *Cribroelphidium*, *Guttulina*, and *Lobatula*, indicate restricted, shallow marine, nearshore conditions. Their most characteristic species show distinct affinities with Eocene faunas of New Zealand and Patagonia, as well as with stratigraphically younger Antarctic foraminiferal communities.

Received 7 December 2011, accepted 9 February 2012, first published online 3 April 2012

Key words: benthic foraminifera, microfossils, Paleogene, West Antarctica

Introduction

Foraminifera are among key microfossils for palaeoenvironmental studies and stratigraphy. However, our knowledge on their pre-Quaternary record from Antarctica is far from satisfactory. Oligocene–Pleistocene foraminifera are relatively well known from the Ross Sea region (e.g. Leckie & Webb 1985, Strong & Webb 2001, Webb & Strong 2006, as well as several more publications by these authors) as an aftermath of large international drilling projects. Moreover, Pliocene deposits from the McMurdo Dry Valleys were also studied for foraminifera (Webb 1974). East Antarctic foraminifera have been less researched. Pliocene assemblages were described from Larsemann and Vestfold hills (Quilty *et al*. 1990, Quilty 2010), whereas reworked Palaeogene foraminifera were described from the shelf of East Antarctica (Quilty 2001). Foraminiferal studies from pre-Quaternary sediments of West Antarctica are also fragmentary. Oligocene planktonic (Gaździcki 1989) and Miocene benthic foraminiferal assemblages (Birkenmajer & Łuczkowska 1987) were reported from King George Island, South Shetland Islands. Pliocene assemblages were found on Cockburn Island, Antarctic Peninsula (Gaździcki & Webb 1996). Until recently, we have had no information on Eocene foraminiferal communities from West Antarctica. Here, we present foraminiferal data from early Eocene strata of Isla Marambio, Antarctic Peninsula, taking the first step to fill this gap.

The Eocene La Meseta Formation (LMF), exposed in the north-eastern part of Isla Marambio (Fig. 1), is a sequence of shallow-marine, deltaic and/or estuarine, poorly consolidated sandstones and siltstones, accumulated within an incised valley (Sadler 1988, Porębski 1995, Marenssi *et al*. 1998, Marenssi 2006). The LMF is approximately 700 m thick, and it is well known for its exceptional fossil record, which provides a unique insight into Eocene life in what has become a harsh polar environment. Throughout the formation, abundant and diverse microfossils, invertebrates, vertebrates, and plants occur in a number of fossiliferous horizons (Feldmann & Woodburne 1988, Stilwell & Zinsmeister 1992, Gaździcki 1996, Francis *et al*. 2006, López Cabrera & Olivero 2011). Among microfossils, foraminifera are very rare in the LMF. So far, only a few specimens of *Cibicides* encrusting brachiopod shells were reported (Bitner 1996) from Telm2 (equivalent to Acantilados Allomember *sensu* Marenssi *et al*. 1998). In this paper, we describe rich foraminiferal communities from the very base of the LMF (Fig. 2a), Telm1 or Valle de las Focas Allomember *sensu* Marenssi *et al*. (1998), which is interpreted as early Eocene in age, 52–54 Ma (Marenssi 2006, López Cabrera & Olivero 2011).

Methods

Fieldwork was carried out by A. Gaździcki during the Argentine-Polish field campaigns on Isla Marambio during the summers of 1987–88, 1991–92, and 1993–94. Rock samples were collected throughout Eocene strata from the north-east side of the island (Fig. 1). After a pilot study, carried out throughout the LMF, detailed study focused on samples from near the base of the section, where some foraminifera were encountered (Fig. 2). Rock samples of approximately 1.5 kg were mechanically crushed and treated with a standard Glauber salt procedure. Disintegrated samples were washed through a series of sieves and dried. Fractions greater than 63 μm were searched for microfossils. All foraminifera were picked and mounted on micropalaeontological slides. Selected specimens of each taxon were investigated under SEM. Generic classification

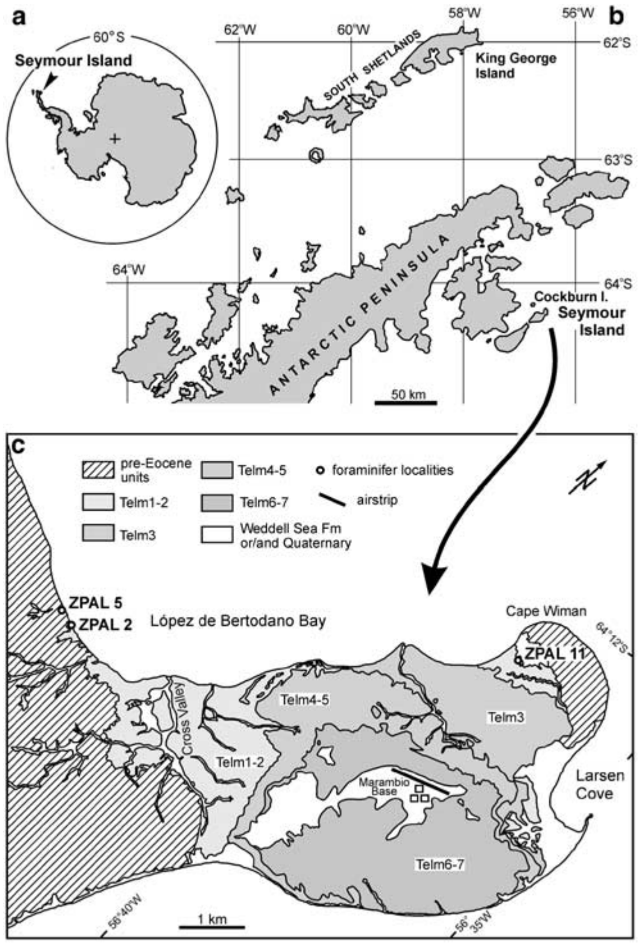

Fig. 1. Geological map of Isla Marambio showing collection sites from the La Mesesta Formation used in this investigation.

was based on Loeblich & Tappan (1987). The investigated collection is housed at the Institute of Paleobiology of the Polish Academy of Sciences (Warszawa) under the catalogue number ZPAL F.55.

Results

Foraminifera were found in three samples. Diverse foraminiferal assemblages are present at two locations: ZPAL 2 (64°15'22.530"S, 56°44'22.103"W, 2.2 m a.s.l.), and ZPAL 5 (Fig. 1), however, the later is by far richer (Table I). Only few, poorly preserved specimens were found at ZPAL 11. In total, 1365 foraminiferal specimens were extracted, only three of which represented problematic planktonic forms. Specimens from ZPAL 2 and 11 are shown in Fig. 3 and specimens from ZPAL 5 are shown in Figs 4 & 5. Benthic foraminifera represent at least 26 species and 21 genera. Their assemblages are distinctively different at each location. The assemblage from ZPAL 2 is dominated by *Nonionellina* and *Nonionella*, *Globocassidulina*, *Eilohedra*, and *Cibicides*, while that from ZPAL 5 by *Globocassidulina*, *Cribroelphidium*, *Guttulina*, and *Lobatula*. Only two benthic and all three problematic planktonic foraminifer specimens were found at the most north-eastern location ZPAL 11. They are poorly preserved, making their precise identification rather problematic.

Taxonomical notes

Some problematic taxa from the LMF are briefly discussed below, according to their alphabetical order.

Cibicides aff. *ungerianus* (d'Orbigny, 1846). Our specimens (Fig. 4.16) seem to represent *C. ungerianus* as shown by Schröder-Adams (1991) in pl. 3, figs 5 & 6. However, she provided no side view. Our specimens differ from the holotype pictured by d'Orbigny by rounded, only slightly compressed margin (Fig. 4.16b).

Cribroelphidium aff. *lauritaense* (Todd et Kniker, 1952). Numerous specimens are present in ZPAL 5 (Fig. 5.3–5.7). In their inflated outline, acutely rounded periphery, number of chambers per whorl, and distributions of sutural bridges, they closely resemble *Elphidium lauritaense* described by Todd & Kniker (1952, pl. 3, fig. 38a & b), from which our specimens differ by more compressed periphery.

Cribroelphidium aff. *saginatum* (Finlay, 1939). Our specimens (Fig. 5.1 & 5.2, and perhaps Fig. 3.11) are inflated, with broadly rounded periphery, and have 4–6 broadly inflated sutural bridges per suture in adult chambers. They show more compressed profile and more irregular ornamentation as compared to the type specimen of Finlay (1939).

Cribroelphidium sp. A single specimen (Fig. 3.12) from ZPAL 11 differs from other specimens of this genus by larger apertures and much broader profile. Unfortunately, its poor preservation prevents precise classification.

Globorosalina sp. A single specimen from ZPAL 5 (Fig. 4.9) resembling *Globorotalia reissi* Loeblich & Tappan, 1957 reported from New Zealand (Jenkins 1971) that ranged practically throughout the entire Lower Eocene (Hornibrook *et al*. 1989). It shows distinctively less depressed sutures than *Globorotalia reissi* of Loeblich & Tappan (1957), which was assigned to *Praepararotalia perclara* Loeblich & Tappan, 1957 and interpreted as of benthic habitat (Liu *et al*. 1998). It appears that our specimen belongs to genus *Globorosalina* established for late Eocene forms from Western Australia (Quilty 1981).

Lobatula sp. In our material, strongly ornamented forms of *Lobatula* (Fig. 4.14 & 4.15, and possibly Fig. 3.8) dominate. They show ornamentation as in specimen of Brady (1884, pl. 93, fig. 5) classified by Jones (1994) as *Cibicides lobatulus*. Typical individuals of *Lobatula lobatula* (Walker & Jacob, 1798) with no ornamentation (Jones 1994, pl. 93, fig. 1) are also present in the LMF (Fig. 4.12 & 4.13), but they are significantly less abundant. For counts of both forms refer to Table I.

https://doi.org/10.1017/S095410201200020X Published online by Cambridge University Press

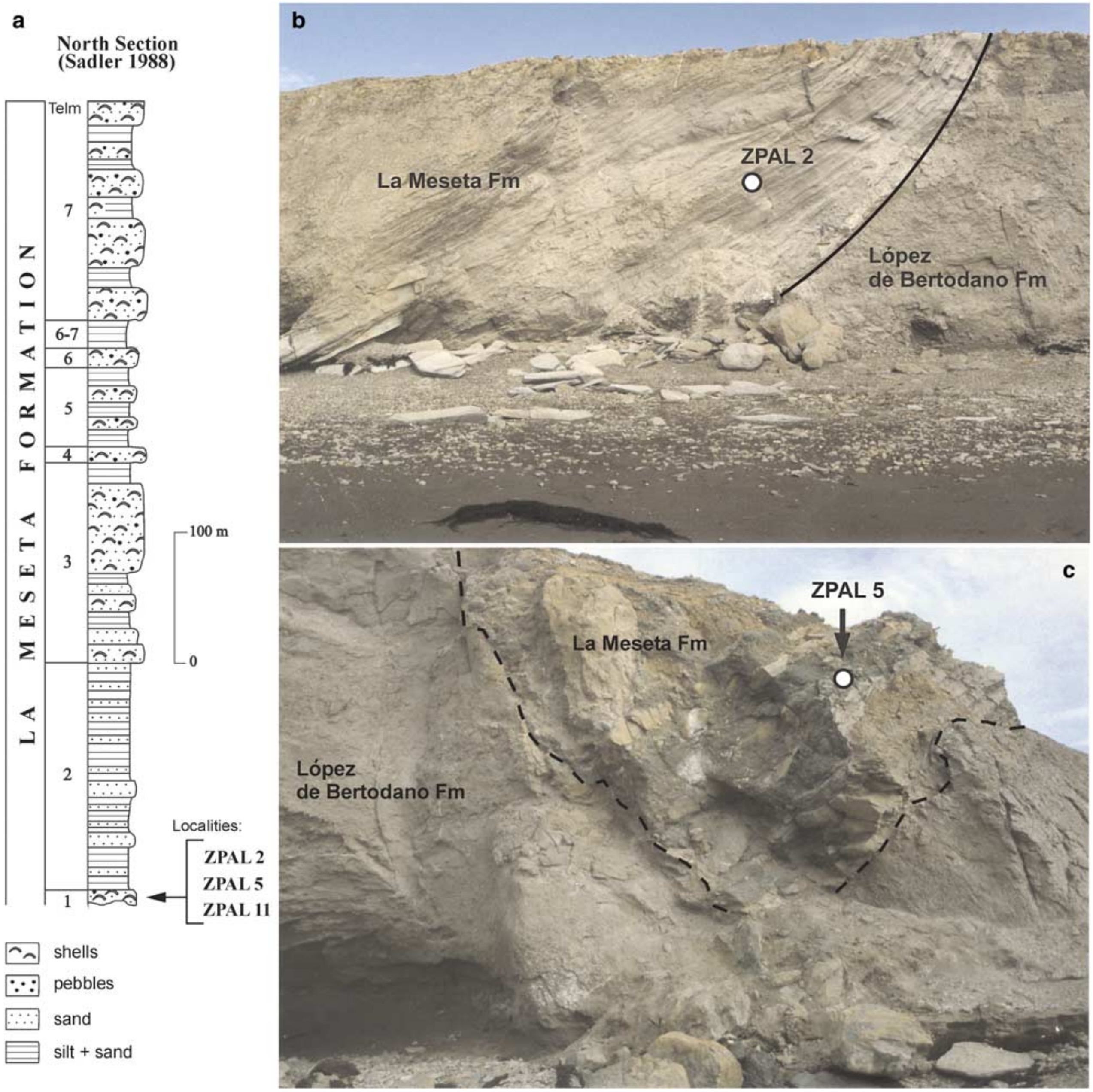

Fig. 2. a. Composite stratigraphic column of the La Meseta Formation on Isla Marambio (north section) adapted from Sadler (1988), showing the main lithofacies and location of samples with foraminifera. Photographs of **b.** site ZPAL 2, and **c.** site ZPAL 5, taken in 1994.

Neoflabellina sp. (Fig. 4.2). It is represented by three specimens, all incomplete. Almost spherical proloculus and planispiral coil of early chambers are seen in uncoated specimens.

?*Nonionellina* sp. In ZPAL 2 and ZPAL 5, modest populations of *Nonionidae* are present. They appear to include two forms, more slender representing *Nonionella bradyi* (Chapman, 1916) (Figs 3.3 & 5.9) as well as slightly larger and less elongated in side view classified here as ?*Nonionellina* sp. (Figs 3.2 & 5.8). The latter do show, however, a considerable morphologic variability. The specimen from ZPAL 2 (Fig. 3.2) shows planispiral last coil typical for *Nonionellina* as well as granules in umbilical area. On the other hand, the specimen from ZPAL 5 (Fig. 5.8) exhibits slightly trochospiral final coil and no granules. Therefore, it is probable that this artificial taxon may represent more than a single species. Unfortunately, our specimens are often compacted and having umbilical area

Table I. Foraminiferal counts from three samples collected from the La Meseta Formation.

	ZPAL 2	ZPAL 5	ZPAL 11
Anomalinoides spissiformis		1	
Astrononion echolsi		2	
Bucella sp.		18	
Bulimina karpatica	1		
Bulimina sp.	1	6	
Cibicides aff. *ungerianus*		6	
Cibicides williamsoni	4		
Cribroelphidium aff. *lauritaense*		354	
Cribroelphidium aff. *saginatum*		40	1
Cribroelphidium sp.			1
Discorbinella sp.		1	
Eilohedra vitrea	5	1	
Globocassidulina subglobosa	5	448	
Globorosalina sp.		1	
Guttulina irregularis		216	
Gyroidina zelandica	1		
Lenticulina inornata		6	
Lobatula lobatula		20	
Lobatula sp.	1	179	
Neoflabellina sp.		3	
Nonionella bradyi	5	6	
?*Nonionellina* sp.	15	10	
Quinqueloculina sp.		1	
Stomatorbina sp.		1	
?*Saracenaria* sp.		1	
?*Trochammina* sp.	1		
?Planktonic foraminifera			3
Total	39	1321	5

filled with sediment. Therefore, it is impossible to observe their full morphologic variability.

Quinqueloculina sp. This taxon is represented by a single, incomplete specimen (Fig. 4.1).

?*Saracenaria* sp. It is represented by a single incomplete specimen (Fig. 4.7). It differs from typical *Saracenaria* by lacking triangular section of latter, rectilinear chambers.

?*Trochammina* sp. It is represented by a single specimen that was significantly flattened by compaction (Fig. 3.1). It is the only agglutinated foraminifer found in our samples. Its poor preservation prevents establishing its precise taxonomic position. It cannot be ruled out that it is redeposited from underlying strata of the López de Bertodano Formation where diverse agglutinated benthic foraminifera were encountered (Huber 1988).

?Planktonic foraminifera. Three specimens come from ZPAL 11. Two incomplete specimens, including one lacking the last chamber (Fig. 3.14), show biconvex outline with weak keel. According to these characteristics, they may represent genus *Planorotalites*. However, its strongly encrusted outer wall and overall outline bears resemblance with *Morozovella lensiformis* Subbotina 1953, as pictured in Pearson *et al.* (2006, pl. 11.9). Another specimen from the same sample shows general globorotalid architecture (Fig. 3.13). Due to its test dissolution and recrystallization, it is difficult to classify.

Discussion

Preservation of foraminiferal assemblages

The two most fossiliferous samples, ZPAL 2 and ZPAL 5, came from coastal cliffs along López de Bertodano Bay west from Cross Valley (Fig. 1c), where the lowermost part of the LMF (Telm1) is exposed. At that location, it cuts into underlying Cretaceous-Palaeocene deposits of the López de Bertodano Formation rich in benthic and planktonic foraminifera (Huber 1988). Nevertheless, foraminifera from ZPAL 2 and ZPAL 5 sites of the LMF are distinctively different in taxonomic composition and appear to represent *in situ* assemblages. They include decent numbers of taxa and specimens that are all similarly well preserved, taking into account rather invasive method of extracting specimens from rock samples. Moreover, the two assemblages are distinctively different, showing few dominating species and a number of accessory taxa (Table I), as is observed among modern living populations, e.g. Majewski (2005).

The few specimens from sample ZPAL 11 from near Cape Wiman (Fig. 1c) are poorly preserved. They show signs of dissolution and recrystallization, which together with their very low abundance may suggest they are not *in situ*. The specimen of *C.* aff. *saginatum* (Fig. 3.11) is definitely the best preserved foraminifer from this sample and may correspond with the assemblage from ZPAL 5. In contrast, problematic planktonic foraminifera found at ZPAL 11, were not encountered at the two other sites and are all poorly preserved. They differ distinctively from planktonic foraminifera described from the underlying López de Bertodano Formation (Huber 1988).

There is also an important question why foraminifera, so abundant in the two samples ZPAL 2 and 5 from the very base of the LMF (Telm1), are practically absent throughout the rest of the Eocene deposits on Isla Marambio. Higher in the LMF (Telm2), only a few specimens of *Cibicides* were reported (Bitner 1996), however, they were found encrusting brachiopod shells. Other abundant calcareous microfossils (ostracods) are also limited to Telm1. Only a single ostracod specimen was reported from Telm7 (Szczechura 2001). On the other hand, rich calcareous macrofossils are present throughout the LMF (Feldmann & Woodburne 1988, Stilwell & Zinsmeister 1992, Gaździcki 1996) testifying to a marine setting. It appears, that there was no environmental reason for the absence of foraminifera, thus, they were most probably destroyed during diagenetic processes after deposition. However, there are no clear lithological variations throughout the LMF (see Fig. 2) that could simply explain that variability in preservation.

Palaeonvironmental interpretation

The two foraminiferal assemblages from ZPAL 2 and 5 include almost exclusively hyaline taxa that are characteristic for inner shelf, marine lagoons, and estuarine temperate

https://doi.org/10.1017/S095410201200020X Published online by Cambridge University Press

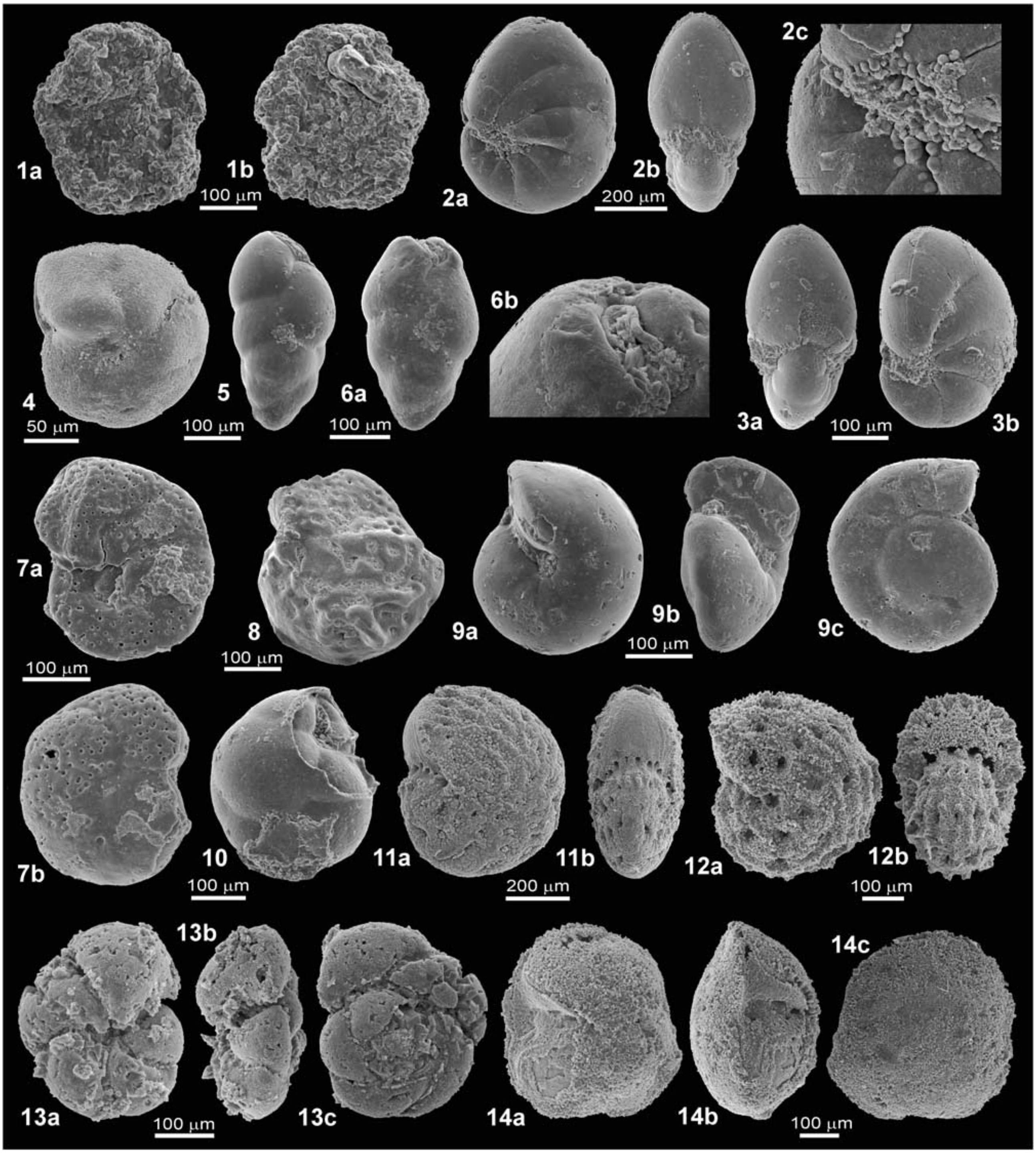

Fig. 3. SEM images of foraminifera from site ZPAL 2: **1.** ?*Trochammina* sp., **2.** ?*Nonionellina* sp., **3.** *Nonionella bradyi* (Chapman, 1916), **4.** *Eilohedra vitrea* (Parker, 1953), **5.** *Bulimina* sp., **6.** *Bulimina karpatica* Szczechura et Pożaryska, 1974, **7.** *Cibicides williamsoni* Garrett, 1941, **8.** *Lobatula* sp., **9.** *Gyroidina zelandica* Finlay, 1939, **10.** *Globocassidulina subglobosa* (Brady, 1884), and ZPAL 11: **11.** *Cribroelphidium* aff. *saginatum* (Finlay, 1959), **12.** *Cribroelphidium* sp., **13.** ?globorotalid, **14.** ?*Planorotalites* sp.

environments (Murray 2006). Numerous *Cribroelphidium* and *Lobatula* found in the ZPAL 5 assemblage may suggest shallower and more turbid water conditions than for ZPAL 2. However, *C. saginatum* is known from throughout New Zealand, where it was interpreted to live in normal marine salinity at upper and mid bathyal depths between *c.* 200 and 2000 m (Hayward *et al*. 1997), which was rather unusual for this genus. In New Zealand assemblages,

https://doi.org/10.1017/S095410201200020X Published online by Cambridge University Press

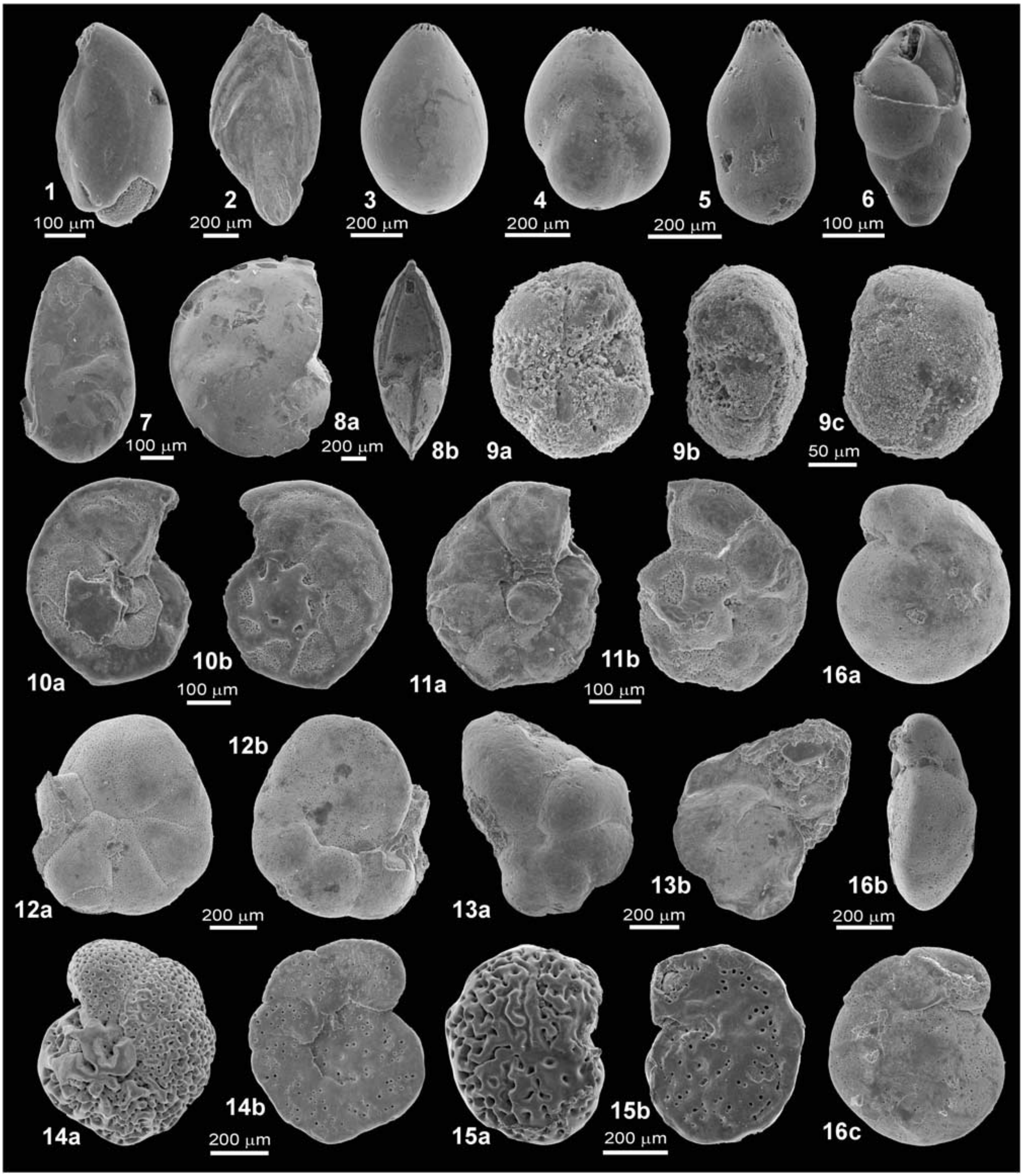

Fig. 4. SEM images of foraminifera from site ZPAL 5: **1.** *Quinqueloculina* sp., **2.** *Neoflabellina* sp., **3.–5.** *Guttulina irregularis* (d'Orbigny, 1846), **6.** *Bulimina* sp., **7.** ?*Saracenaria* sp., **8.** *Lenticulina inornata* (d'Orbigny, 1846), **9.** *Globorosalina* sp., **10.** *Stomatorbina* sp., **11.** *Discorbinella* sp., **12. & 13.** *Lobatula lobatula* (Walker et Jacob, 1798), **14. & 15.** *Lobatula* sp., **16.** *Cibicides* aff. *ungerianus* (d'Orbigny, 1846).

it constituted only up to 10% of the total benthic foraminifera, whereas in ZPAL 5 it amounted to 30%, which may suggest more restricted conditions. Moreover, the lack of planktonic foraminifera in ZPAL 2 and ZPAL 5 supports restricted, shallow marine, nearshore conditions at the western limits of the LMF on Isla Marambio.

https://doi.org/10.1017/S095410201200020X Published online by Cambridge University Press

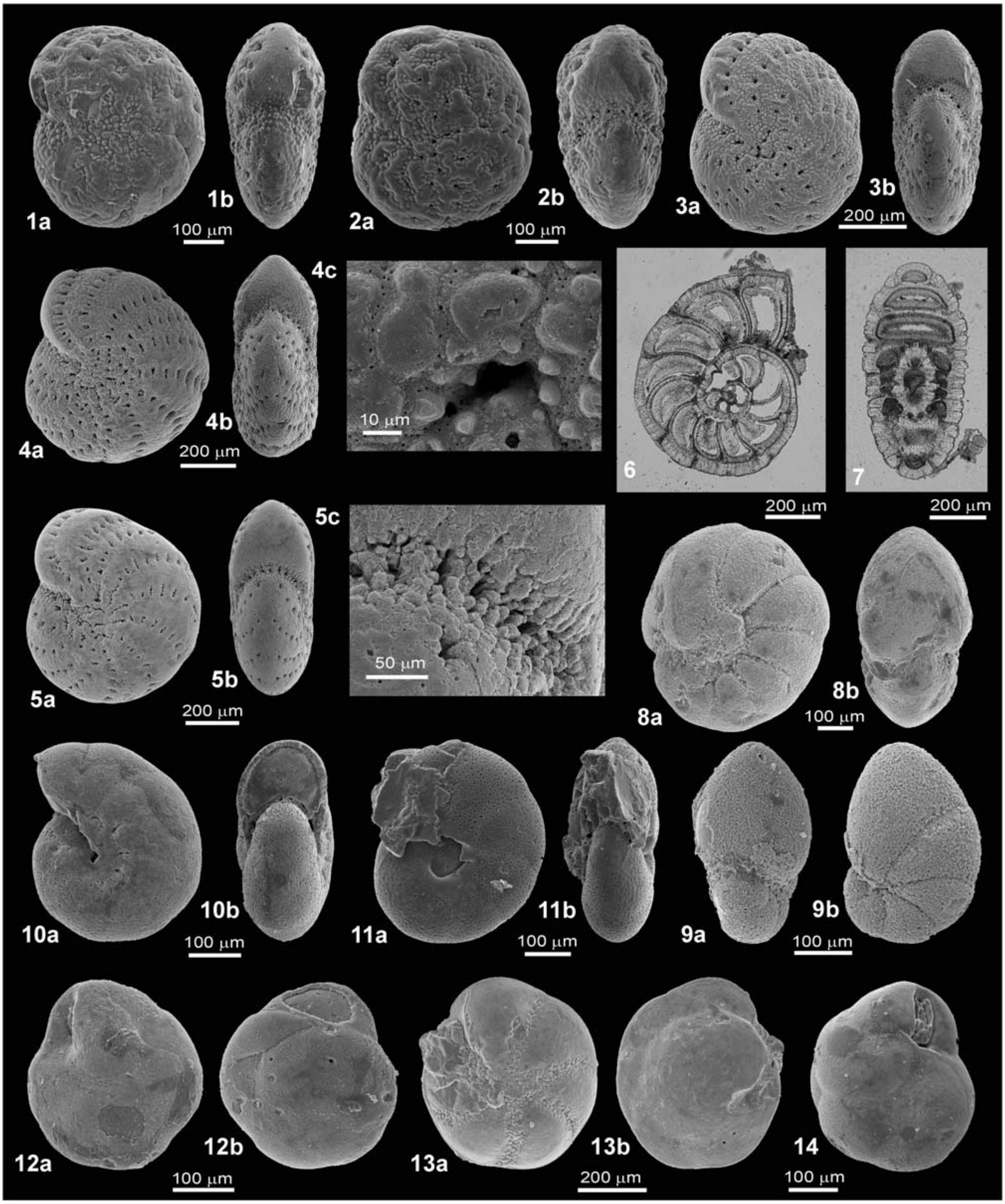

Fig. 5. SEM images of foraminifera from site ZPAL 5: **1. & 2.** *Cribroelphidium* aff. *saginatum* (Finlay, 1939), **3.–7.** *Cribroelphidium* aff. *lauritaense* (Todd et Kniker, 1952): **4c.** single aperture, **5c.** apertures in the last suture, **6.–7.** equatorial and axial sections, **8.** ?*Nonionellina* sp., **9.** *Nonionella bradyi* (Chapman, 1916), **10.** *Astrononion echolsi* Kennett, 1967, **11.** *Anomalinoides spissiformis* (Cushman et Stainforth, 1945), **12.** *Eilohedra vitrea* (Parker, 1953), **13.** *Buccella* sp., **14.** *Globocassidulina subglobosa* (Brady, 1884).

https://doi.org/10.1017/S095410201200020X Published online by Cambridge University Press

This interpretation is in good agreement with the stratigraphic position of the lowest unit of the LMF, Telm1. It is only 2 m thick and consists of gray to red-brown limonitic, glauconitic, sandy siltstones and pebble conglomerates. These developed as a result of accumulation on an erosional surface, cut into Cretaceous-Palaeocene deposits of the López de Bertodano Formation. This surface was flooded during an early Eocene transgressive cycle (Porębski 1995, Marenssi *et al*. 1998). This suggests a restricted, shallow marine habitat.

It appears that at the north-eastern end of the Eocene exposures, at ZPAL 11 (Fig. 1c), there might have been more influence of open marine conditions. The three potentially planktonic foraminifera constitute half of all specimens collected at that site, however, scarcity and poor preservation of these finds may suggest that they represent reworked material, thus having no palaeoenvironmental significance.

Biogeography

Foraminiferal finds of early and mid Palaeogene age from Antarctica are very sparse, therefore it is difficult to relate our assemblages to contemporaneous fauna from nearby geographic locations. Some reworked Palaeogene foraminifera are known from the East Antarctic shelf (Quilty 2001), unfortunately, they lack original population structure and seem to represent mixed associations. Microfauna described from ODP sites at high (Schröder-Adams 1991) and mid southern latitudes (e.g. Boersma 1985, Nomura 1991), represent deep water biota, rich in *Uvigerinidae*, and share only limited number of cosmopolitan species with the LMF, i.e. *L. lobatula*, *C. ungerianus*, and *Eilohedra vitrea* (Parker, 1953).

On the other hand, during the Eocene, due to the geographic proximity of Antarctica, Australia, New Zealand, and South America, a considerable overlap in species composition occurred between these regions (Quilty 2001). For comparison with foraminifera from the LMF, it is especially important that in all these regions, relatively shallow water habitats existed. The faunal links between Southern Hemisphere landmasses are well exhibited by the most characteristic component of foraminiferal assemblage from the LMF, *Cribroelphidium*. *Cribroelphidium lauritaense* and *C. saginatum* are known from the Eocene of Patagonia (Todd & Kniker 1952, Malumián 1990) and New Zealand (Finlay 1939, Hayward *et al*. 1997). *Guttulina irregularis* (d'Orbigny, 1846), also very common in the LMF, was encountered in Patagonian Eocene deposits by Todd & Kniker (1952) as well. *Cribroelphidium lauritaense* and *G. irregularis* seem to indicate rather shallow water habitat, as they were not noted from Eocene deep water archives (Boersma 1985, Nomura 1991, Schröder-Adams 1991).

It is also important to note, that another abundant species (Table I) *Globocassidulina subglobosa* (Brady, 1884) along with some less numerous (*E. vitrea*, *L. lobatula*, *N. bradyi*, *Astrononion echolsi* Kennett, 1967) long-ranging species were reported from Oligocene-Miocene strata from the Ross Sea (e.g. Leckie & Webb 1985, Strong & Webb 2001). These taxa remained an important component of Antarctic foraminiferal assemblages until recently (Ward 1984, Majewski 2005).

Conclusions

Benthic foraminiferal assemblages from the LMF of Isla Marambio are the first Eocene foraminiferal communities reported from West Antarctica. Their recognition is an important step in reconstructing evolution of Antarctic foraminifera. Two distinctive communities were found at two locations. They represent *in situ* assemblages inhabiting restricted, shallow water, nearshore environments. The more abundant assemblage from ZPAL 5, dominated by *G. subglobosa*, *C.* aff. *lauritaense*, *G. irregularis*, *Lobatula* sp., and *C.* aff. *saginatum* may suggest shallower and more turbid water conditions than the assemblage from ZPAL 2, dominated by *Nonionellina* sp., *N. bradyi*, *G. subglobosa*, and *E. vitrea*. The most characteristic foraminifera of the earlier assemblage, the two species of *Cribroelphidium* are known only from Eocene formations of New Zealand and Patagonia. A number of other species from the LMF are long-ranging taxa reported from stratigraphically younger Antarctic rocks that are typical also for modern Antarctic foraminiferal communities.

Acknowledgements

We would like to thank Bruce W. Hayward and Brian T. Huber for their reviews, which helped to improve the manuscript. Fieldwork on Isla Marambio was supported by the Instituto Antártico Argentino and the Fuerza Aerea Argentina. The latest stages of this study were supported by a grant of the Polish Ministry of Science and Higher Education No. 2011/01/B/ST10/06956.

References

Birkenmajer, K. & Łuczkowska, E. 1987. Foraminiferal evidence for a Lower Miocene age of glaciomarine and related strata, Moby Dick Group, King George Island (South Shetland Islands, Antarctica). *Studia Geologica Polonica*, **90**, 81–123.

Bitner, M.A. 1996. Encrusters and borers of brachiopods from the La Meseta Formation (Eocene) of Seymour Island, Antarctica. *Polish Polar Research*, **17**, 21–28.

Boersma, A. 1985. Biostratigraphy and biogeography of Tertiary bathyal benthic foraminifers: Tasman Sea, Coral Sea, and on the Chatham Rise (Deep Sea Drilling Project, Leg 90). *Initial Reports of the Deep Sea Drilling Project*, **90**, 961–1037.

Brady, H.B. 1884. Report on the foraminifera dredged by H.M.S. Challenger during the years 1873-1876. *Report of the Scientific Results of the Voyage of H.M.S. Challenger, 1873-1876. Zoology*, **9**, 1–814.

Feldmann, R.M. & Woodburne, M.O., eds. 1988. *Geology and paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America Memoir*, No. 169, 566 pp.

Finlay, H.J. 1939. New Zealand foraminifera: key species in stratigraphy. No. 2. *Transactions of the Royal Society of New Zealand*, **69**, 89–128.

Francis, J.E., Pirrie, D. & Crame, J.A., eds. 2006. *Cretaceous-Tertiary high latitude palaeoenvironments, James Ross Basin, Antarctica. Special Publication of the Geological Society of London*, No. 258, 206 pp.

Gaździcki, A. 1989. Planktonic foraminifera from the Oligocene Polonez Cove Formation of King George Island, West Antarctica. *Polish Polar Research*, **10**, 47–55.

Gaździcki, A., ed. 1996. Paleontological results of the Polish Antarctic Expeditions. Part II. *Palaeontologia Polonica*, **55**, 192 pp.

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

Hayward, B.W., Hollis, C.J. & Grenfell, H.R. 1997. Recent Elphidiidae (Foraminiferida) of the south-west Pacific and fossil Elphidiidae of New Zealand. *Institute of Geological and Nuclear Sciences Monograph*, **16**, 166 pp.

Hornibrook, N.D., Brazier, R.C. & Strong, C.P. 1989. Manual of New Zealand Permian to Pleistocene foraminiferal biostratigraphy. *New Zealand Geological Survey Paleontological Bulletin*, **56**, 1–175.

Huber, B.T. 1988. Upper Campanian-Paleocene foraminifera from the James Ross Island region, Antarctic Peninsula. *In* Feldmann, R.M. & Woodburne, M.O. *eds. Geology and paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America Memoir*, No. 169, 163–252.

Jenkins, D.G. 1971. New Zealand planktonic foraminifera. *New Zealand Geological Survey Paleontological Bulletin*, No. 42, 1–278.

Jones, R.W. 1994. *The Challenger foraminifera*. Oxford: Oxford University Press, 149 pp.

Leckie, R.M. & Webb, P.-N. 1985. Late Paleogene and early Neogene foraminifers of DSDP Site 270, Ross Sea, Antarctica. *Initial Reports of the Deep Sea Drilling Project*, **90**, 1093–1142.

Liu, C., Olsson, R.K. & Huber, B.T. 1998. A benthic paleohabitat for *Praepararotalia* gen. nov. and *Antarcticella* Loeblich and Tappan. *Journal of Foraminiferal Research*, **28**, 3–18.

Loeblich Jr, A.R. & Tappan, H. 1957. Planktonic foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic coastal plains. *United States National Museum Bulletin*, **215**, 173–198.

Loeblich Jr, A.R. & Tappan, H. 1987. *Foraminiferal genera and their classification*. New York: Van Nostrand Reinhold, 970 pp.

López Cabrera, M.I. & Olivero, E.B. 2011. An Eocene articulated Polyplacophora (Mollusca) from the La Meseta Formation, Antarctica and the stratigraphy of the fossil-bearing strata. *Journal of Paleontology*, **85**, 970–976.

Majewski, W. 2005. Benthic foraminiferal communities: distribution and ecology in Admiralty Bay, King George Island, West Antarctica. *Polish Polar Research*, **26**, 159–214.

Malumián, N. 1990. Foraminíferos bentónicos de la localidad tipo de la Formación La Despedida (Eoceno, Isla Grande de Tierra del Fuego). Parte II. Nodosariacea, Buliminacea, Elphidiidae y rotálidos tuberculados. *Ameghiniana*, **27**, 343–363.

Marenssi, S.A. 2006. Eustatically controlled sedimentation recorded by Eocene strata of the James Ross Basin, Antarctica. *In* Francis, J.E., Pirrie, D. & Crame, J.A. *eds. Cretaceous-Tertiary high latitude palaeoenvironment, James Ross Basin, Antarctica. Special Publication of the Geological Society of London*, No. 258, 125–133.

Marenssi, S.A., Santillana, S.N. & Rinaldi, C.A. 1998. Stratigraphy of the La Meseta Formation (Eocene) Marambio (Seymour) Island, Antarctica. *In* Casadío, S. *ed. Paleógeno de América del Sur y de la Peninsula Antártica. Revista Asociación Paleontológica Argentina, Publication Especial*, **5**, 137–146.

Murray, J. 2006. *Ecology and application of benthic foraminifera*. Cambridge: Cambridge University Press, 426 pp.

Nomura, R. 1991. Paleoceanography of upper Maestrichtian to Eocene benthic foraminiferal assemblages at sites 752, 753, and 754, eastern Indian Ocean. *Proceedings of the Ocean Drilling Project, Scientific Results*, **121**, 3–29.

Pearson, P.N., Olsson, R.K., Huber, B.T., Hemleben, C. & Berggren, W.A., eds. 2006. Atlas of Eocene planktonic foraminifera. *Cushman Foundation for Foraminiferal Research, Special Publication*, **41**, 514 pp.

Porębski, S.J. 1995. Facies architecture in a tectonically-controlled incised-valley estuary: La Meseta Formation (Eocene) of Seymour Island, Antarctic Peninsula. *Studia Geologica Polonica*, **107**, 7–97.

Quilty, P.G. 1981. Late Eocene benthic Foraminiferida, south coast, Western Australia. *Journal of the Royal Society of Western Australia*, **64**, 79–100.

Quilty, P.G. 2001. Reworked Paleocene and Eocene foraminifera, Mac. Robertson Shelf, East Antarctica: paleoenvironmental implications. *Journal of Foraminiferal Research*, **31**, 369–384.

Quilty, P.G. 2010. Foraminifera from late Pliocene sediments of Heidemann Valley, Vestfold Hills, East Antarctica. *Journal of Foraminiferal Research*, **40**, 193–205.

Quilty, P.G., Gillieson, D., Burgess, J., Gardiner, G., Spate, A. & Pigeon, R. 1990. *Ammoelphidiella* from the Pliocene of Larsemann Hills, East Antarctica. *Journal of Foraminiferal Research*, **20**, 1–7.

Sadler, P.M. 1988. Geometry and stratification of uppermost Cretaceous and Paleogene units on Seymour Island, northern Antarctic Peninsula. *In* Feldmann, R.M. & Woodburne, M.O., *eds. Geology and paleontology of Seymour Island, Antarctic Peninsula. Geological Society of America Memoir*, No. 169, 303–320.

Schröder-Adams, C.J. 1991. Middle Eocene to Holocene benthic foraminifer assemblages from the Kerguelen Plateau (southern Indian Ocean). *Proceedings of the Ocean Drilling Project, Scientific Results*, **119**, 611–630.

Stilwell, J.D. & Zinsmeister, W.J. 1992. Molluscan systematics and biostratigraphy: lower Tertiary La Meseta Formation, Seymour Island, Antarctic Peninsula. *Antarctic Research Series*, **55**, 192 pp.

Strong, C.P. & Webb, P.-N. 2001. Lower Oligocene foraminiferal fauna from CRP-3 drillhole, Victoria Land Basin, Antarctica. *Terra Antartica*, **8**, 347–358.

Szczechura, J. 2001. Ostracods from the Eocene of Seymour Island, Antarctic Peninsula. *Palaeontologia Polonica*, **60**, 157–181.

Todd, R. & Kniker, H.T. 1952. An Eocene foraminiferal fauna from the Agua Fresca Shale of Magallenes Province, southernmost Chile. *Cushman Foundation for Foraminiferal Research, Special Publication*, **1**, 1–28.

Ward, B.L. 1984. *Distribution of modern benthic foraminifera of McMurdo Sound, Antarctica*. MSc thesis, Victoria University, Wellington, 211 pp. [Unpublished.]

Webb, P.-N. 1974. Micropaleontology, paleoecology, and correlation of the Pecten Gravels, Wright Valley, Antarctica, and description of *Trochoelphidiella onyxi* n. gen et n. sp. *Journal of Foraminiferal Research*, **4**, 184–199.

Webb, P.-N. & Strong, C.P. 2006. Foraminiferal biostratigraphy and palaeoecology in Upper Oligocene-Lower Miocene glacial marine sequences 9, 10, and 11, CRP-2/2A drill hole, Victoria Land Basin, Antarctica. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **231**, 71–100.