



Rare calcareous microfossils from Middle Miocene strata, Weddell Sea off Antarctic Peninsula

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Abstract: The calcareous microfossil assemblage from Middle Miocene strata of SHALDRIL Site NBP0602A-5D consists of benthic foraminifera, ostracods, bivalves, and gastropods, and is interpreted as shallow-water. It appears to be reworked but its age is probably similar to the age of the host sediment, which contains only rare, fragmented, agglutinated foraminifera. Most of the calcareous taxa are of uncertain taxonomic affiliation, due to the scarcity of Cenozoic microfossils of this age from West Antarctica, and also the very different paleohabitat of this now extinct assemblage.

Key words: West Antarctica, benthic foraminifera, ostracods, gastropods, reworking.

Introduction

Despite being of great value for paleoenvironmental reconstructions and stratigraphy, very little is known of calcareous Tertiary microfossils from West Antarctica. Paleogene foraminifera are known only from Seymour Island, where Cretaceous–Paleocene assemblages were reported by Huber (1988), and early Eocene benthic foraminifera by Gaździcki and Majewski (2012). Moreover, Oligocene planktonic (Gaździcki 1989) and Miocene benthic foraminiferal assemblages (Birkenmajer and Łuczowska 1987) were described from King George Island, South Shetland Islands. Stratigraphically younger, Miocene–Pliocene and Pliocene benthic assemblages were illustrated from James Ross (Jonkers *et al.* 2002) and Cockburn islands (Gaździcki and Webb 1996) east of the Antarctic Peninsula. Ostracods have been described from only some of these localities, including Eocene strata of Seymour Island (Szczuchura 2001), Oligocene strata of the Polonez Cove Formation on King George Island (Błaszyk 1987), and Pliocene strata of Cockburn Island (Szczuchura and Błaszyk 1996). Bivalves and gastropods are known mostly from Eocene strata of Seymour Island (Stilwell and

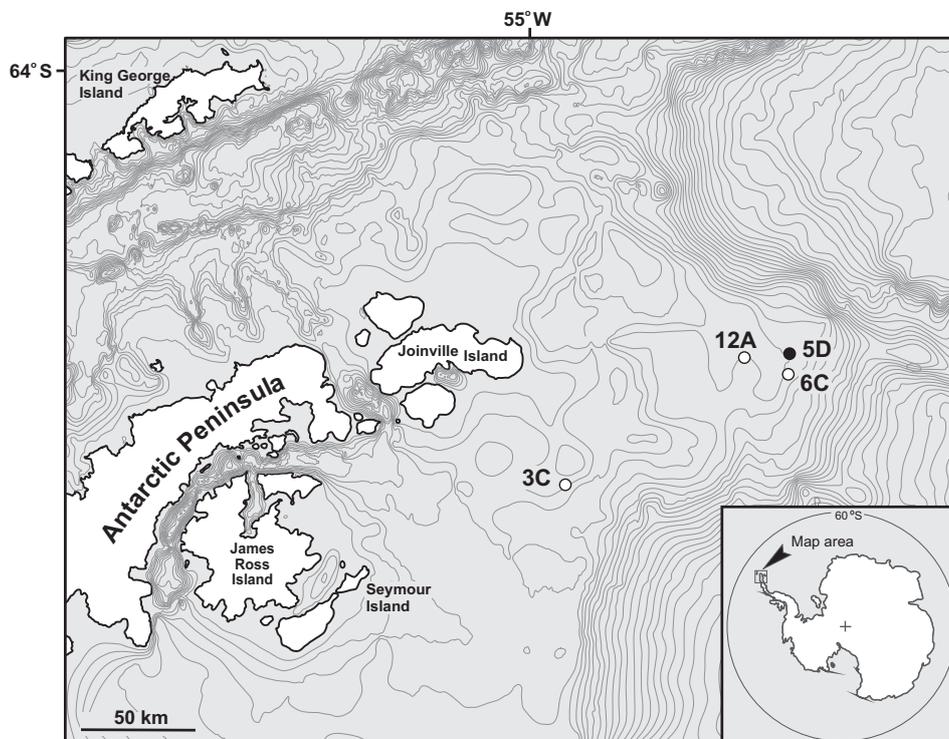


Fig. 1. Location map of four sites of SHALDRIL Leg NBP0602A investigated in this study. Site 5D, marked with the solid circle, yielded the calcareous microfossil assemblage discussed throughout this study.

Zinsmeister 1992, and references therein) and from Miocene strata of King George Island (Karczewski 1987; Quaglio *et al.* 2010).

There are many reasons why these findings are so limited. First, marine Tertiary deposits are scarce in the region, and if present they often reflect paleoenvironments and diagenetic conditions unfavorable for carbonate preservation. Of nearly one hundred samples from four pre-Holocene sections investigated in this study, calcareous microfossils were found in a single sample only. Although the microfossil association presented in this study is limited in number of taxa and specimens, and displays only moderate preservation, it is unlike any other previously described assemblage. Thus, it provides a unique record of extinct micro-biota and may help in understanding their Cenozoic evolution.

Methods

During SHALDRIL II cruise in 2006, pre-Quaternary strata were recovered at four sites; NBP0602A-3, 5, 6, and 12 (Fig. 1). Eighty samples of *c.* 10–15 g of dry

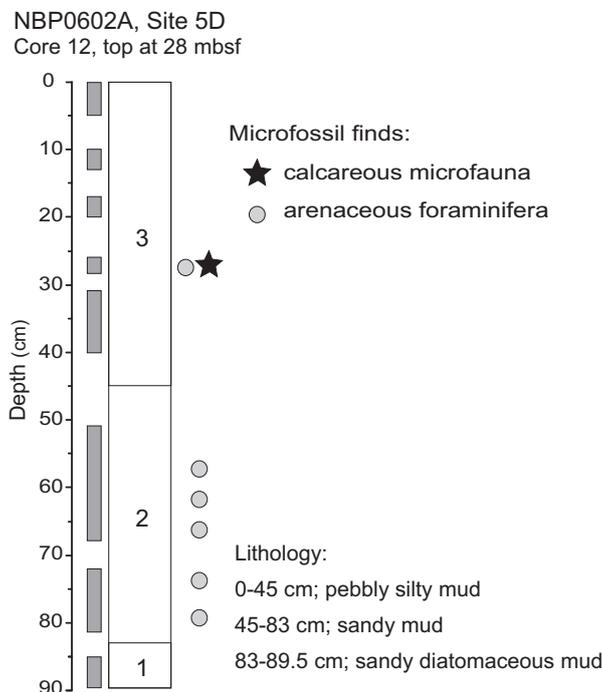


Fig. 2. Section 5D-12R_a targeted by subsequent sampling; sampled intervals marked in gray.

mass were collected every *c.* 40 cm throughout the most complete cores 3C, 6C, 5D and 12A, targeting all major lithologic units. All samples were soaked in tap water, washed through a set of sieves and dried. Fractions greater than 63 μm were searched for microfossils. All calcareous microfossils, as well as agglutinated foraminifera, were picked and mounted on micropaleontological slides. Selected specimens of each taxon were investigated under SEM. All specimens are housed at the Institute of Paleobiology of the Polish Academy of Sciences (Warszawa) under the catalogue number ZPAL F64.

Diverse calcareous microfossils were encountered only in a single sample from interval 26–28 cm of section 5D-12R_a. After the initial study, the rest of the 5D-12R_a section was sampled, except intervals with no preserved material (Fig. 2). Total dry mass of these additional samples amounted to 513 g. All samples were processed in the same manner.

Results

Diverse, but sparse, calcareous microfossils were found only in a single sample 5D-12R_a, from 26–28 cm, including benthic foraminifera (Table 1), ostracods, gastropods and bivalves, along with fine calcareous detritus including articulated

Table 1
 Benthic foraminifera from section 5D-12 of Site NBP0602A-5

Taxon / Interval (cm)	26–28	56–58	58–60	60–64	64–68	72–77	77–82
? <i>Biasterigerina</i> sp.	2						
<i>Criboelphidium</i> sp.	1						
? <i>Elphidium</i> sp.	1						
<i>Elphidium</i> cf. <i>macellum</i>	11						
<i>Quinqueloculina</i> sp.	1						
? <i>Triloculina</i> sp.	5						
<i>Loeblichopsis sabulosa</i>	3	2	8	3	3	11	2
<i>Miliammina arenacea</i>				1			

echinoid spines and shell fragments. In several additional samples from this section (Fig. 2), a few, mostly fragmented specimens of agglutinated foraminifera were found; however, no additional calcareous microfossils were encountered. Images of all taxa are shown on Figs 3–6.

Benthic foraminifera. — ?*Biasterigerina* sp. (Fig. 3.7–8). This convex foraminifer with a slightly concave umbilical side bears a resemblance to *Biasterigerina*, *Boltovskoyella*, or to a lesser degree with some compressed Rosalinidae, e.g. *Neoconorbina*. Although detailed morphology of both specimens is obscured by recrystallization, their low spire suggests the closest affinity with the earliest.

Criboelphidium sp. (Fig. 3.9). The single incomplete specimen has a chamber shape and arrangement of septal openings similar to forms of the *Criboelphidium excavatum* group; however, it lacks papillae ornamenting sutural pits and the base of apertural face. Thus, it resembles *Criboelphidium lene* (Cushman *et* McCulloch, 1940) but shows more chambers in the final whorl and a distinctively lower apertural face. In this regard, it is a morphological variant of modern *Elphidium macellum* from Patagonian fjords (Pillet *et al.* 2012, fig. 1F) (see below, the discussion for *Elphidium* cf. *macellum*).

?*Elphidium* sp. (Fig. 3.14). Poor preservation of this incomplete specimen prevents precise systematic identification. Its delicate ornamentation resembles that of *Elphidiella arctica* (Parker *et* Jones, 1864) as pictured by Loeblich and Tappan (1987, pl. 790, figs 11–12); however, it lacks indications of two rows of openings at the sutures typical of *Elphidiella*.

Elphidium cf. *macellum* (Fichtel *et* Moll, 1798) (Fig. 3.10–13). In overall shape and ornamentation, this taxon resembles specimens of modern *E. macellum* from Patagonian fjords (Pillet *et al.* 2012). Our specimens differ by the indications of spinal bases in the keel area in large specimens (Fig. 3.12–13), which resembles *Elphidium pseudoinflatum* Cushman, 1936 as shown by Hayward *et al.* (1997, pl. 15, fig. 15). According to these authors, in *E. pseudoinflatum*, septal bridges do not extend the full way across each chamber. This is also the case for our smaller speci-

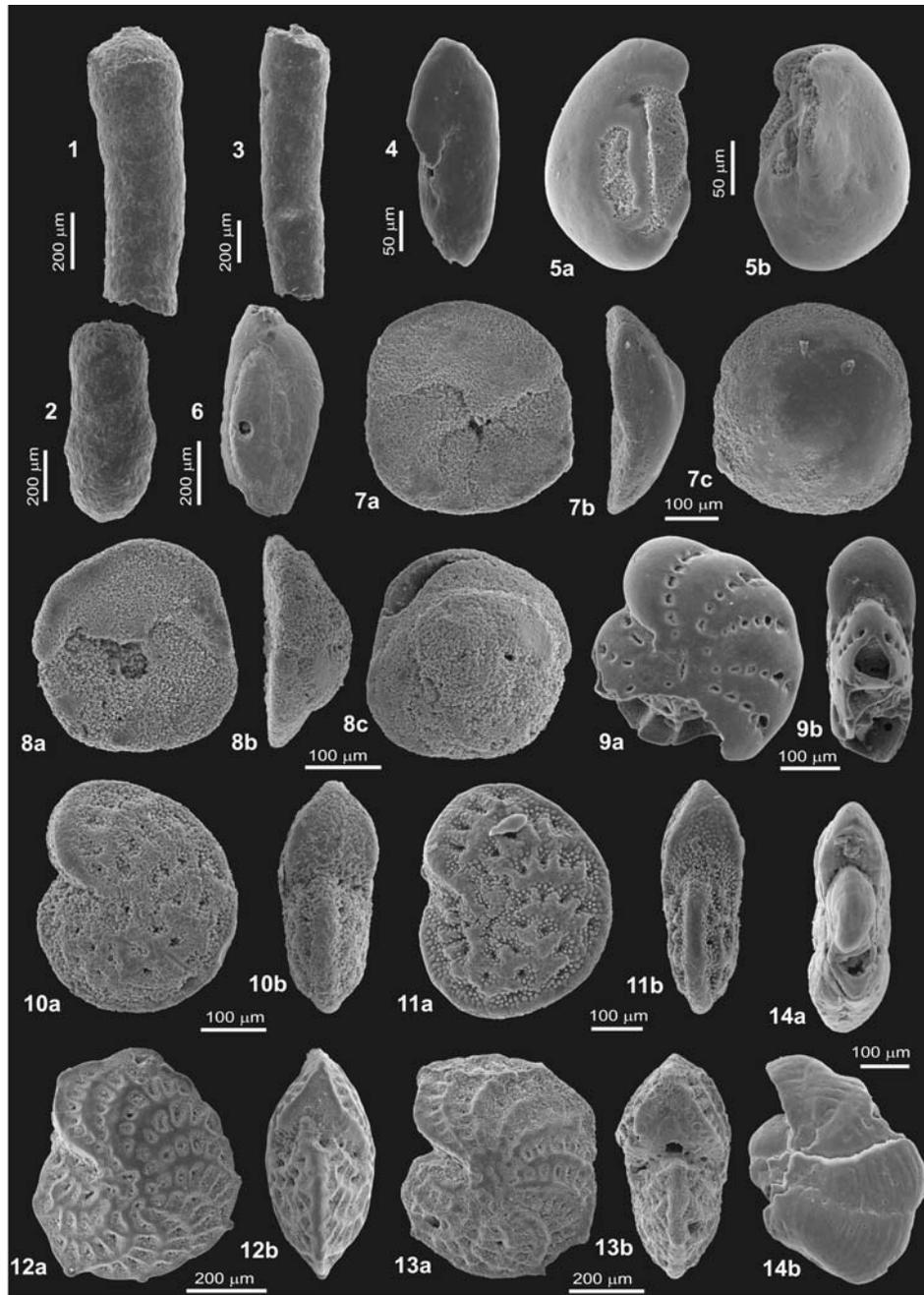


Fig. 3. Foraminiferal specimens from section 5D-12 R_a, Site NBP0602A-5. **1–3.** *Loeblichopsis sabulosa* (Brady, 1881) 58–60 cm, 60–64 cm, 58–60 cm. **4.** *Miliammina arenacea* (Chapman, 1916), 60–64 cm. **5.** *?Triloculina* sp. **6.** *Quinqueloculina* sp. **7, 8.** *?Biastrigerina* sp. **9.** *Criboelphidium* sp. **10–13.** *Elphidium* cf. *macellum* (Fichtel et Moll, 1798). **14.** *?Elphidium* sp. Specimens 5 through 14 all from sample 26–28 cm.

mens (Fig 3.10–11); however, the latest molecular work indicates that recent *E. macellum* from Patagonian fjords has a strongly variable morphology and some specimens show septal bridges extending only partially across each chamber (Pillet *et al.* 2012, fig. 1D). Moreover, our specimens differ from *E. pseudo-inflatum*, as discussed by Hayward *et al.* (1997, pl. 15, figs 12–18), by having a significantly less acute periphery and wider keel, again showing close similarity to modern *E. macellum*.

Loeblichopsis sabulosa (Brady, 1881) (Fig. 3.1–3). This species is represented by several, fragmented specimens from various samples (see samples marked by circles on Fig. 2). Only a single unarticulated specimen was found (Fig. 3.2). This foraminifer is known from modern North Atlantic sediments (Murray and Taplin 1984), where it was originally described, as well as from Ross Sea, Antarctica (Fillon 1974).

Miliammina arenacea (Chapman, 1916) (Fig. 3.4). The presence of only a single incomplete specimen from 5D-12R_a, 60–64 cm does not allow detailed morphological analysis of this taxon. The specimen in Fig. 3.4 is smaller in size and slenderer than Holocene specimens of *M. arenacea* from West Antarctica (e.g. Majewski 2005, Majewski and Anderson 2009). Nevertheless, it shows the same overall characteristics.

Quinqueloculina sp. (Fig. 3.6). This includes a single incomplete specimen that resembles *Quinqueloculina seminula* (Linnaeus, 1758).

?*Triloculina* sp. (Fig. 3.5). This includes several fragmented specimens with no diagnostic morphological details.

Ostracods. — Two taxa represented by three specimens are briefly discussed below.

Callistocythere sp. (Fig. 4.1–2). This genus is represented by two left valves. They show irregular ribs forming an open reticulate meshwork with shallow to moderately deep fossae with dense secondary punctuation. Internal characters are typical of the extant genus *Callistocythere*, which first appeared in the Paleogene. Its hinge is entomodont, inner lamella wide, central muscle scar comprising four adductors in a vertical row and large ovate frontal scar. The specimen illustrated on Fig. 4.1 appears to differ from the second one in wider ribs and rare fossae preserved in the central area of the valve. However, this may be due to imperfect preservation of this specimen. The specimens from the Weddell Sea differ from other species of *Callistocythere* by the presence of wide and rounded ribs and small fossae in the central area. In surface sculpture, they resemble *Callistocythere pusztafaluensis* Pietrzeniuk, 1973 from the Late Miocene of the Tokaj Mountains (Northern Hungary) (Pietrzeniuk 1973).

Cypridocopina gen. et sp. indet. (Fig. 4.3). Only a posterior part of the left valve of this specimen was preserved. The muscle scar and hinge structure are poorly visible, but appear to be similar to cypridocopine taxa. This taxon is somewhat similar to representatives of *Argilloecia* (Propontocyprididae).

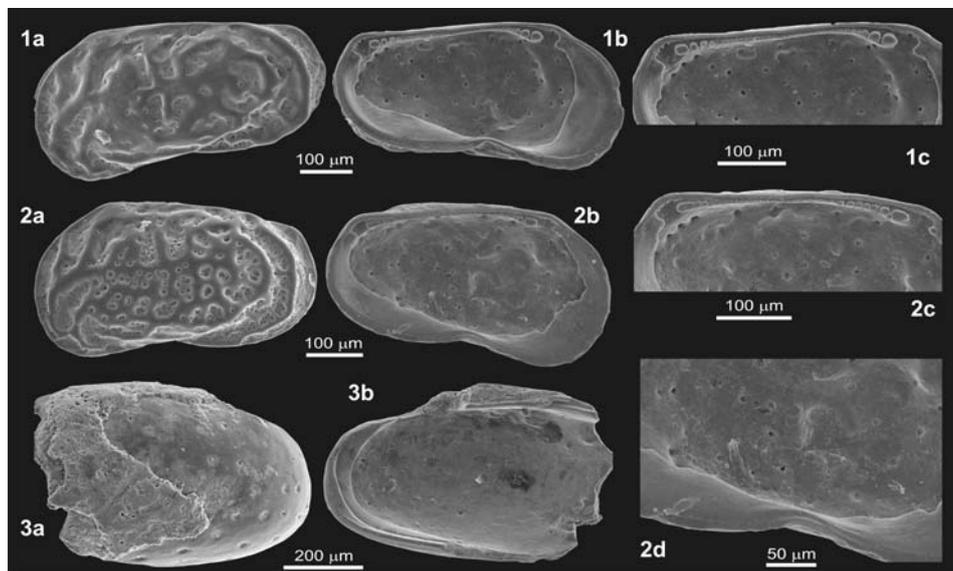


Fig. 4. Ostracods from 26–28 cm interval of section 5D-12 R_a, Site NBP0602A-5. **1, 2.** *Callistocythere* sp. LV I lateral view (1a); LV in internal view (1b); close-up showing hinge structure (1c); LV in lateral view (2a); LV in internal view (2b); close-up showing hinge structure (2c); close-up showing central muscle field (2d). **3.** Cypridocopina gen. et sp. indet. in lateral (3a) and internal (3b) views.

Mollusks. — Mollusks are represented by two species of bivalves (Fig. 5) and three species of gastropods (Fig. 6). The identifications provided below are preliminary pending further investigation.

The bivalves are poorly preserved veliconchs. The exact identification is not possible but it is suggested that one of the bivalves is an arcoid (Fig. 5.1), while the other is nuculoid (Fig. 5.2), based on the long taxodont hinge in the former and triangular ? taxodont hinge in the latter. In the second case, the taxonodonty is not clearly visible, therefore heterodont affinity is also possible. The gastropods are represented by a single shell of omalogyrid *Retrotortina* (Fig. 6.1–3), a single cerithiid (Fig. 6.5) similar to *Bittium*, *Bittiolum*, *Argyropeza*, and *Varicopeza*, and three specimens of caenogastropod (Fig. 6.4) similar to *Benthonella* or *Haloceras*.

Retrotortina is an extremely small heterobranch gastropod belonging to the family Omalogyridae (Gofas and Warén 1998). The diameter of our specimen is only 0.34 mm with 0.2 mm of the protoconch. *Retrotortina* is hyperstrophic (*i.e.*, pseudosinistral) with a clear deviation from planispiral coiling that separates the genus from *Omalogyra* (Gofas and Warén 1998). Three described species of this genus occur in the East Atlantic (British Isles to Morocco) and Mediterranean (Gofas and Warén 1998), as well as off South Africa and Namibia (Barnard 1969; Rolán *et al.* 2009) in offshore gravelly bottoms in water depths from 20 to 200 m (Gofas and Warén 1998) and in the intertidal pools on algae (Rolán *et al.* 2009). The shell from Weddell Sea (Fig. 6.4) is most likely a new species of *Retrotortina*.

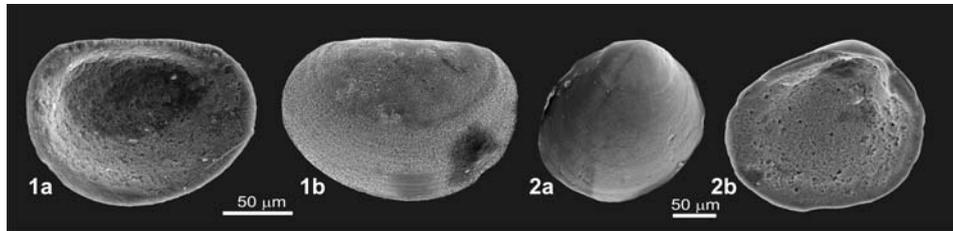


Fig. 5. Bivalve veliconchs from 26–28 cm interval of section 5D-12 R_a, Site NBP0602A-5. **1.** Possible arcoid in ventral (1a) and dorsal (1b) views. **2.** Possible nuculoid in ventral (2a) and dorsal (2b) views.

The cerithiid (Fig. 6.5) is a juvenile shell 1.15 mm high and 0.77 mm in diameter. It consists of 3.5 whorls of larval shell and two whorls of the teleoconch. Therefore the exact identification is difficult as numerous cerithiids (*e.g.*, *Bittium*, *Bittiolium*, *Argyropeza* and *Varicopeza*) display similar juvenile whorls. Those genera differ mainly in the morphology of H peristome (as far as the shell is concerned) and soft parts (Houbrick 1980a, b, 1993). It is therefore not possible to further classify these shells. *Argyropeza* and *Varicopeza* are mostly deep-water cerithiids (~30–1000 m and 10–700 m respectively) occurring in the Indo-Pacific (Houbrick 1980a, b), while species of *Bittium* and *Bittiolium* occur abundantly both in shallow- and relatively deep water habitats in East and West Atlantic respectively, though similar taxa are also known from the Indo-Pacific (Houbrick 1993).

The third gastropod species in the sample is the most elusive. We failed to find a direct match in the existing literature. The species is represented by three juvenile specimens (Fig. 6.1–3); one of those (Fig. 6.1) is very well preserved and displays a larval shell composed of two whorls 0.42 mm of diameter. The protoconch is characterized in the sutural area by a conspicuous larval projection (Fig. 6.1d), a structure that is thought to serve as a mechanical defense covering the head of the swimming veliger (Hickman 2001). The most similar taxa are the rissoid *Benthonella* and vanicoroid *Haloceras* (Warén and Bouchet 1991; Bouchet and Warén 1993). Both taxa have very large (0.6–2.3 mm) protoconchs keeled in the sutural area, but the presence of a larval projection is not obvious. Because of the latter and the generally smaller size of the protoconch, this identification is speculative. The most similar taxa are deep water inhabitants (down to 5000 m; Warén and Bouchet 1991; Bouchet and Warén 1993).

Interpretation

Despite detailed sampling of most of the 5D-12R_a section, as well as repeated sampling of the 27–28 cm interval, the calcareous foraminiferal assemblage was found only in a single sample taken from the interval 26–28 cm. No other calcareous specimens were found, although fragmented arenaceous foraminifers do oc-

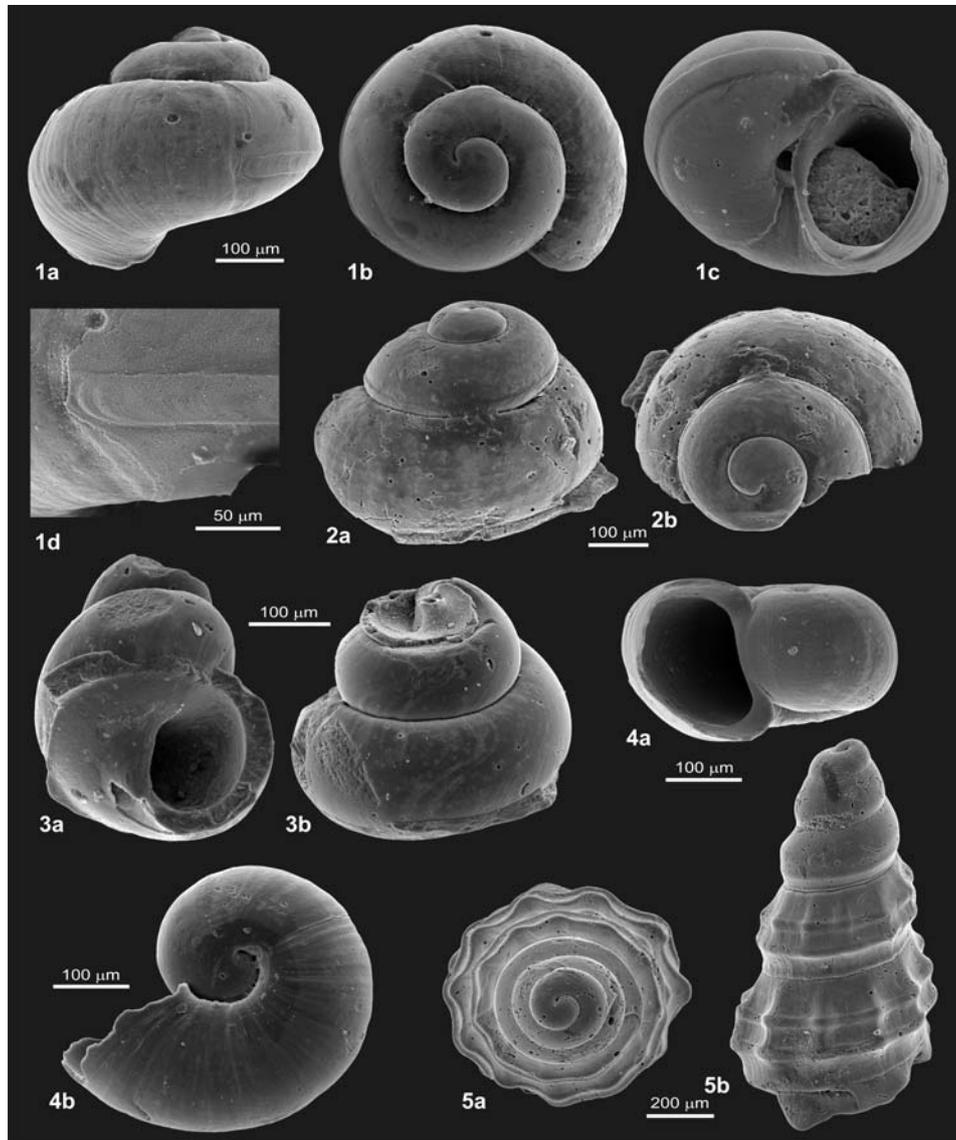


Fig. 6. Gastropods from 26–28 cm interval of section 5D-12 R_a, Site NBP0602A-5. **1–3**. Unidentified caenogastropod similar to *Benthonella* and *Haloceras*. Three different specimens are shown in lateral (1a), apical (1b), and apertural (1c) views, 1d is a close-up of the larval projection; in lateral (2a) and apical (2b) views; and in apertural (3a) and lateral (3b) views. **4**. *Retrotortina* sp. in apertural (4a) and umbilical (4b) views. **5**. Unidentified cerithiid in apical (5a) and lateral (5b) views.

cur, mostly belonging to *Loeblichopsis sabulosa*, along with a single specimen of *Miliammina arenacea* (Table 1, Fig. 2). They appear to be *in situ*, a residual part of probably a more diverse assemblage. Unfortunately, low numbers of these specimens prevents reliable interpretation. Both, *L. sabulosa* and *M. arenacea* show a

similar type of finely agglutinated wall built on an organic base (Loeblich and Tappan 1987), which is relatively resistant to corrosive conditions. *Miliammina arenacea* is known for its uniquely high preservation potential (*e.g.* Schmiedl *et al.* 1997; Majewski and Anderson 2009), being insoluble in acids (Loeblich and Tappan 1987).

The rarity of the calcareous microfossils suggests that they are not *in situ*, and could have been transported within a sediment clast. However, very little of the original sediment remains. A few remnants do react with hydrochloric acid, but seem to be devoid of nannofossils based on our SEM examination. Long-distance transport of these calcareous microfossils seems unlikely.

It appears that the age of the calcareous assemblage is more or less similar to the age of the host sediment, which is dated at ~12.5 Ma (Anderson *et al.* 2011). Although *E. macellum* was reported from Patagonian fossil assemblages since at least Early Miocene (Nanez 1990; Malumian and Scarpa 2005; Malumian and Olivero 2006), comparison of our specimens with well-illustrated modern and fossil forms seems to support the Middle Miocene age. Our specimens show intermediate morphology between modern *E. macellum* from the Patagonian fjords (Pillet *et al.* 2012) and *Elphidium pseudoinflatum* known from the Late Eocene to middle Miocene of New Zealand (Hayward *et al.* 1997) (see the taxonomic section for more details).

Paleoenvironmental interpretation of the calcareous foraminiferal assemblage points to rather shallow water, as it is devoid of planktonic forms. Moreover, *Elphidium pseudoinflatum*, the interpreted ancestor of the most abundant specimens in our assemblage, *E. cf. macellum*, is known in New Zealand predominantly from the inner shelf (0–50 m), and at times from depths up to 100 m (Hayward *et al.* 1997). Similarly, modern *E. macellum* is a common species in normal salinity on moderately sheltered beaches and at inner shelf depths around much the southwest Pacific; however, it may be reworked into bathyal depths. In eastern Australia, it is frequently a major component of low tidal and shallow subtidal (0–20 m depth) assemblages (Hayward *et al.* 1997). All Patagonian specimens investigated by Pillet *et al.* (2012) came from intertidal depths. The second most abundant group of calcareous foraminifera are miliolids, which also seem to support a shallow-water environment for this assemblage.

Ostracods may also indicate a shallow water environment. Recent species of *Callistocythere* are known from many littoral environments (Coimbra *et al.* 1995; Warne 2005), *e.g.* from Australia (Warne *et al.* 2006), Argentina (Whatley and Moguilevsky 1975), Brazil (Coimbra *et al.* 1995), and many other locations. The majority of *Callistocythere* species inhabit shallow open marine and marginal marine environments, with highest abundances being in shallow environments (*e.g.* Warne 2005). However, they are also known from brackish-water environments (Whatley and Moguilevsky 1975). In comparison, the gastropods are less supportive of a shallow environment. They could suggest a rather wide range of bathy-

metry, though most likely an outer shelf setting and, if comparisons to *Benthonella* are plausible, even deeper. *Retrotortina* is known to occur in depths from 0 to 200 m, while the discussed cerithiids have a water depth range of 0–1000 m.

The presumed shallow-water provenance of most of the microfossil assemblage may be the reason for problems with taxonomic affiliation of high proportion of taxa discussed in the earlier section. The foraminiferal assemblage, for example, does not include any evolutionary conservative Antarctic genera; such as *Globocassidulina*, *Astrononion*, *Nonionella*, *Eilohedra* and *Lobatula*. These are all known from West Antarctica, at least since early Eocene (Gaździcki and Majewski 2012) and have not changed much until recently (*e.g.* Majewski 2005). This may hint that during Middle Miocene some habitats were very different from today.

Conclusions

Throughout four Cenozoic cores collected during SHALDRIL Leg NBP0602A, a diverse, although low in numbers, calcareous microfossil assemblage was recovered from a single sample from NBP0602A-5D. It seems that this association is not *in situ* and that it was most likely transported within a soft sediment clast that was subsequently disintegrated during sample treatment. In several other samples from near this interval, rare, mostly fragmented specimens of agglutinated foraminifera were also encountered. They are interpreted as remnants of a probably more diverse *in situ* assemblage.

The calcareous assemblage consists of benthic foraminifera, ostracods, bivalves, and gastropods, often of uncertain taxonomic affiliation. Foraminifera are dominated by forms similar to extant *Elphidium macellum*, suggesting that the age of this assemblage is probably close to the age of the host sediment formerly dated at ~12.5 Ma. High numbers of this foraminifer, as well as miliolids, together with the lack of planktonic foraminifera, suggests a shallow-water paleoenvironment, possibly even as shallow as intertidal or subtidal. This interpretation is supported by ostracods, but only to a lesser degree by mollusks within the same sample. The taxonomic ambiguity of many components of this assemblage may result not only from a scarcity of Cenozoic microfossils reported from West Antarctica, but also from very different paleohabitats that existed in Antarctica during the middle Miocene.

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