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Phymatoderma melvillensis isp. nov. and other trace fossils from the Cape Melville Formation (Lower Miocene) of King George Island, Antarctica

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Abstract: Trace fossils *Phymatoderma melvillensis* isp. nov., *Thalassinoides* isp., ?*Nereites* isp. and *Planolites* isp. are reported from the glacio-marine sediments of the Cape Melville Formation (Lower Miocene) of King George Island, West Antarctica. Their occurrence and strong bioturbation of sediments point to an offshore or deeper (outer shelf or upper slope) environment. Deep marine crab *Antarctidromia inflata* Förster, 1985, has been found in *Thalassinoides* isp. The tracemaker (?crustacean) of *Phymatoderma melvillensis* re-reworked pelletal sediments probably during times of food deficiency.

Key words: Antarctica, King George Island, Cape Melville Formation, ichnofossils, Miocene, glacio-marine strata.

Introduction

Trace fossils from glacio-marine deposits are rarely described, surprisingly, more frequently from the Late Carboniferous–Early Permian Gondwanan glaciations (*e.g.* Eyles *et al.* 1998; Pazos 2002; Shi and Weldon 2002; Chakraborty and Bhattacharya 2005; Buatois *et al*. 2007) than from the Cenozoic glaciations (Armentrout 1979; Aitken 1990; Naldrett 1990a, b, 1993; Eyles and Vossler 1991; Aitken and Hardy 1992; Elyes *et al.* 1992). For the Cenozoic occurrences, most of the data are derive from the Northern Hemisphere.

Fossiliferous glacio-marine deposits of the Lower Miocene Cape Melville Formation (CMF) from King George Island, South Shetlands, West Antarctica (Fig. 1) contain trace fossils which deserve description and interpretation. That is the aim of this paper. The trace fossils have not been reported in detail previously, except for an illustration of a large sub-cylindrical, horizontal burrow, in which a specimen of the

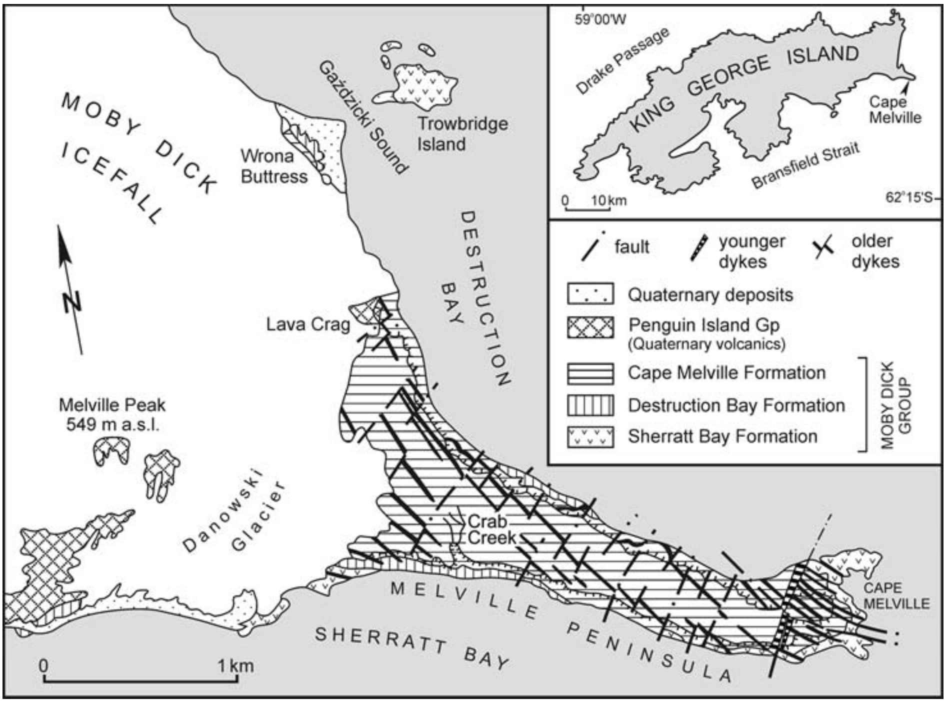

Fig. 1. Geological map of the Cape Melville-Melville Peninsula area, King George Island, South Shetlands, West Antarctica (after Birkenmajer 1984: fig. 2).

crab *Antarctidromia inflata* Förster, 1985 was found (Förster *et al*. 1987), and which was identified as *Thalassinoides* by Birkenmajer (1995). The trace fossil specimens were collected by A.G. and R. Wrona during the 1980/81 and 1985/86 austral summers. The ichnofossil collection is housed at the Institute of Paleobiology of the Polish Academy of Sciences in Warszawa (abbreviated ZPAL Tf.1 and ZPAL Cr.I).

Geological setting

The investigated trace fossils were collected from the erosional top of the Melville Peninsula, King George Island (Figs 1, 2). The CMF (up to 150 m thick, according to Troedson and Riding 2002) consists of horizontally or subhorizontally bedded gray-green-brown mudstone, silty mudstone with siltstone and sandstone intercalations (Birkenmajer 1982, 1987, 2001; Troedson and Riding 2002). The strata contain numerous marine invertebrates (Gaździcki and Wrona 1982, 1986; Birkenmajer *et al.* 1983; Gaździcki ed. 1987; Bitner and Crame 2002; Anelli *et al.* 2006) *in situ,* and also glacial dropstones (up to 2 m), mostly of the Antarctic continent provenance (Gaździcki and Wrona 1982: fig. 9; Birkenmajer and Butkiewicz 1988; Wrona 1989). Recycled Early Cambrian fossiliferous limestone dropstones (Wrona and Zhuravlev 1996; Wrona 2004, 2009) and Cretaceous nannoplankton and belem-

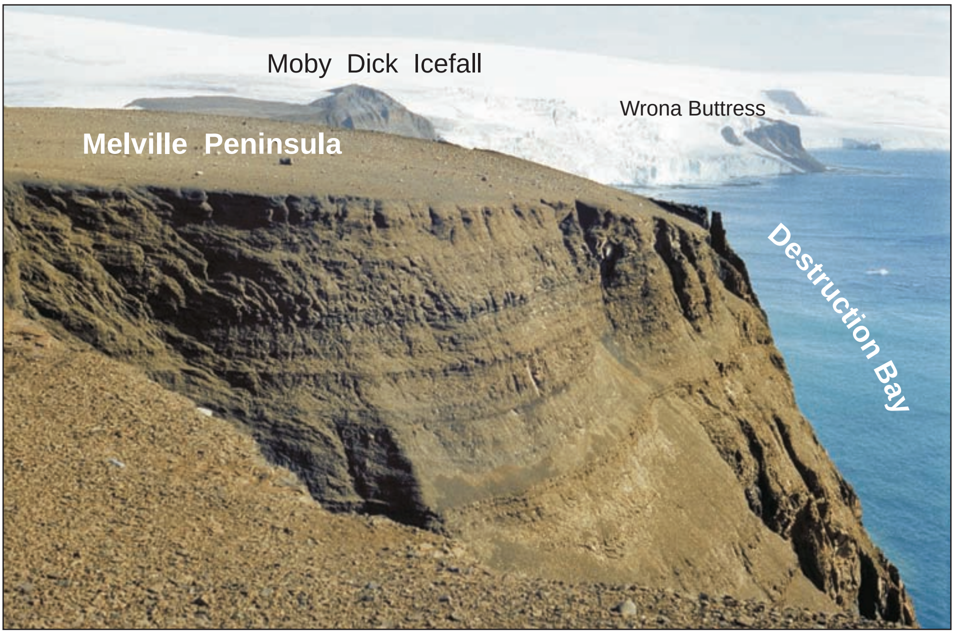

Fig. 2. The north cliff face and top of the Melville Peninsula exposing horizontally stratified glacio-marine strata of the Lower Miocene Cape Melville Formation.

nites (Birkenmajer *et al*. 1987) have been accumulated in the sediments of the CMF as a result of iceberg-rafting during the Early Miocene glacial event – the Melville Glaciation in the Antarctic Peninsula sector (Birkenmajer 1982, 2001).

Radiometrical K-Ar (Birkenmajer *et al.* 1985), strontium isotope $^{87}Sr/^{86}Sr$ (Dingle and Lavelle 1998), as well as dinoflagellate biostratigraphical data (Troedson and Riding 2002) indicate Early Miocene age of the CMF.

Fossil assemblage of *Flabellum* solitary corals (Roniewicz and Morycowa 1987), homolodromid crabs (Förster *et al.* 1985, 1987; Feldmann and Gaździcki 1998), nephropid lobsters (Feldmann and Crame 1998), and aspidostomatid bryozoans (Hara and Crame 2004) from the upper part of the Cape Melville Formation suggest an outer shelf or upper slope setting.

Systematic paleontology

Four different trace fossils have been recognized in the material collected at Melville Peninsula.

Ichnogenus *Phymatoderma* Brongniart, 1849

Diagnosis. — Horizontal to subhorizontal trace fossil composed of irregularly branched lobes spreading out from one point. Edges of the lobes are irregular and can show palmate termination. The lobes are commonly filled with pellets arranged perpendicularly to the longer axes of the lobes (after description by Fu 1991).

Remarks. — *Phymatoderma* was revised and discussed by Fu (1991). It is interpreted as a burrow system produced by deposit-feeders (Seilacher 2007). Fu (1991) regarded the presence of perpendicular pellets as the diagnostic feature of this ichnogenus. However, the pellets can be only locally preserved (Uchman 1999).

Ichnospecies of *Phymatoderma* include *P. granulata* (Schlotheim, 1822), which displays variable branches resembling *Chondrites*, *Phymatoderma alcicorne* (Fischer-Ooster, 1858) with densely packed, symmetrically arranged probes forming half-circle fans, *Phymatoderma penicillum* Uchman, 1999, which is characterized by sparsely packed, thin lobes forming paint brush-like structures at distal parts.

Phymatoderma melvillensis isp. nov.
(Figs 3A, B, 4A, B)

?2004. *Phymatoderma granulata*; Olivero *et al.*: p. 63.

?2007. *Phymatoderma granulata*; Olivero *et al.*: p. 39, fig. 15B, D.

?2007. *Phymatoderma granulata*; (Schlotheim): Ponce *et al.*: p. 260, figs 9D, 10B, D.

Material and types: 8 specimens. Holotype: specimen ZPAL Tf. 1/5 (Fig. 3B). Paratype: specimen ZPAL Tf. 1/6 (Fig. 4A).

Derivation of name: From the Cape Melville Formation.

Diagnosis. — Bunches of cylindrical probes filled with pelleted sediments, which show local meniscate structure.

Description. — Horizontal, straight or slightly winding cylinders, are 8 to 23 mm wide (mean 16.8 mm, n = 14). In a single specimen the width is constant or changes by no more than 10%. The cylinders are elliptical to almost circular in cross section. The cylinders commonly show primary successive, never true branches *sensu* D'Alessandro and Bromley (1987), which display diverging, slightly palmate geometry. Some of the cylinders are crossed by other cylinders. The branches diverge at the angles of 20–40°. The cylinders are filled with dark sediment, which contains densely packed ovoid pellets. These pellets are 2.0–3.0 mm, exceptionally 5 mm long, and 1.0–1.5 mm in diameter. Locally they form meniscate structure, where longer axes of the pellets follow arcs of the menisci (Figs 3B, 4A). In some specimens, the pellets and meniscate structure are only weakly visible. The concave side of menisci faces toward the converging branches.

Remarks. — Regular, meniscate structures are a diagnostic feature of *Taenidium* Heer, 1877 (D'Alessandro and Bromley 1987). Pellets arranged in menisci are diagnostic of *Taenidium dieslingi* (Unger, 1850), formerly *T. satanassi* D'Alessandro and Bromley, 1987 (Uchman 1999). Nevertheless, menisci are present only in some of the analyzed specimens. Therefore, the material cannot be ascribed to *Taenidium*. *Alcyonidiopsis* Massalongo, 1856 is diagnosed as simple or rarely tubular, branched burrows filled with faecal pellets (Uchman 1999), but in the studied

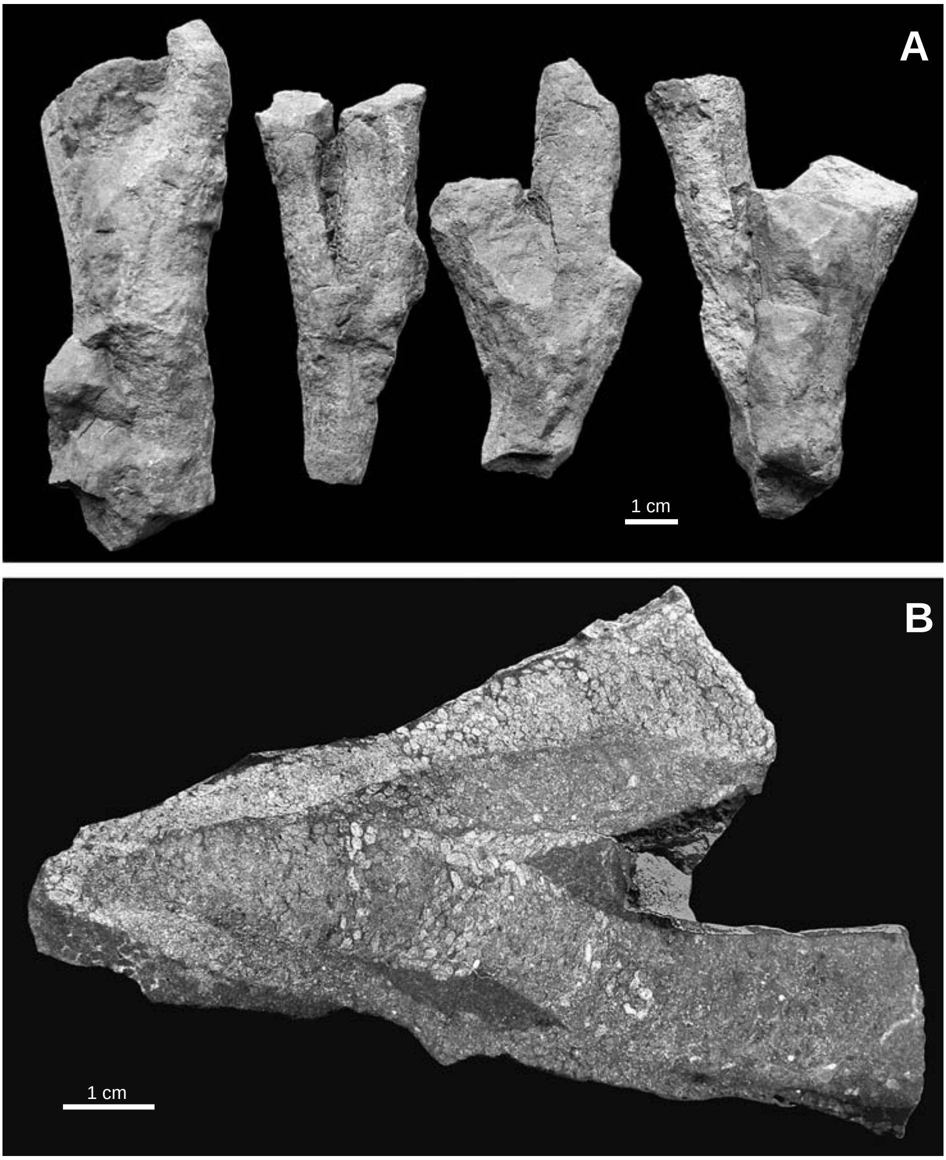

Fig. 3. *Phymatoderma melvillensis* isp. nov. **A**. Specimens (from the left to the right) ZPAL Tf. 1/1, ZPAL Tf. 1/2, ZPAL Tf. 1/3, ZPAL Tf. 1/4. **B**. The holotype, polished surface. Specimen ZPAL Tf. 1/5. Note several stage of reworking and menisci. Cape Melville Formation (Lower Miocene), King George Island.

material the branches do not fit the diagnosis. The overall shape of the described trace fossil resembles also *Phycodes* Richter, 1850 which, however, does not display pelletal and meniscate filling (*e.g.* Fillion and Pickerill 1990). The palmate branches mostly resemble *Phymatoderma* Brongniart, 1849 but it differs from all known ichnospecies of this ichnogenus. *Phymatoderma alcicorne* (Fischer-Ooster, 1858)

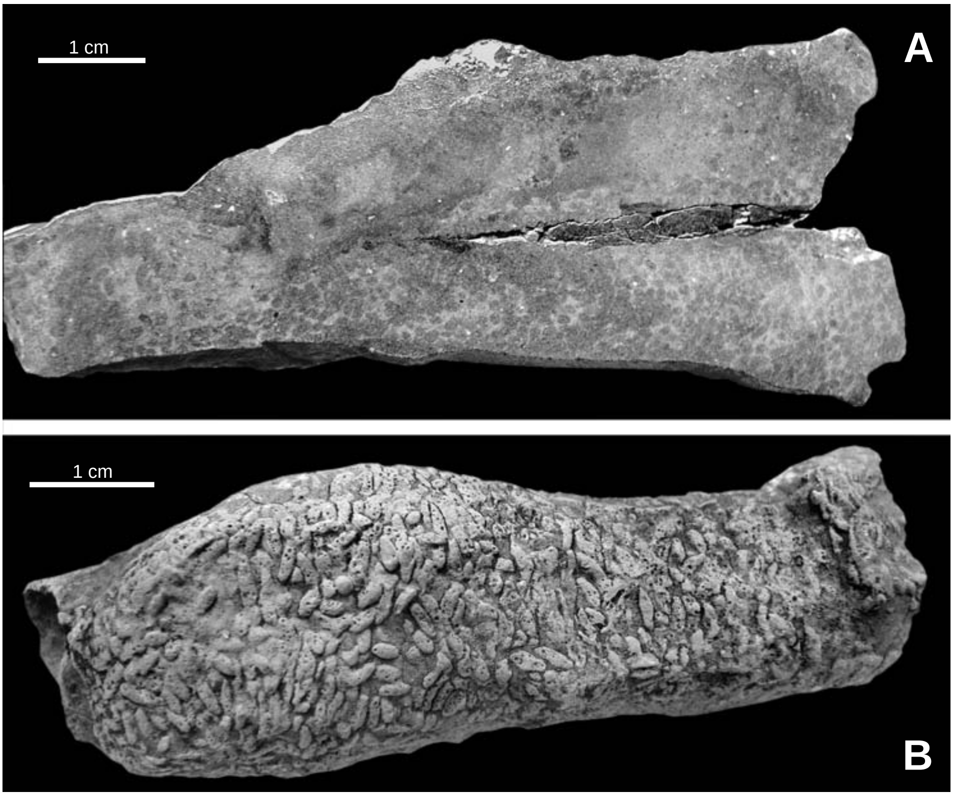

Fig. 4. *Phymatoderma melvillensis* isp. nov. **A**. Specimen ZPAL Tf. 1/6, polished surface. **B**. Specimen ZPAL Tf. 1/7. Note well developed pellets. Cape Melville Formation (Lower Miocene), King George Island.

displays densely packed probing branches forming symmetric half-circle fans (Fu 1991), *Phymatoderma penicillum* Uchman, 1999 is characterized by sparsely packed, thin lobes forming paint brush-like structures distally. *Phymatoderma granulata* (Schlotheim, 1822), displays variable branches resembling *Chondrites* (Fu 1991; Seilacher 2007).

The most similar material occurs in the uppermost Eocene–lowermost Oligocene of the Cerro Colorado Formation in Tierra del Fuego, Argentina (Olivero *et al*. 2007; Ponce *et al*. 2007) and from the Pliocene of Ecuador (Miller and Vokes 1998; Miller and Aalto 1998). They display packed pellets and local menisci and were described as *Phymatoderma granulata*. However, the type material of *P. granulata* from the Lower Jurassic of Germany is different, mostly by having *Chondrites*-like branches (Fu 1991; Seilacher 2007). Probably, the trace fossil from Ecuador and Tierra del Fuego belong *to P. melvillensis*, but this requires further study.

Olivero *et al.* (2004) interpreted the *P. granulata* from Tierra del Fiego as a result of J-shaped causative burrow probing, which movement led to formation of retrusive spreiten packed with pellets. Material in the pellets is selected. Miller and

Aalto (1998) noticed that the pellets were built of material deriving from sediment surface. The pelleted material was reworked latter, probably after microbial maturation during times of food scarcity. Such an interpretation can be applied also to *P. mellvillensis*.

Ichnogenus *Thalassinoides* Ehrenberg, 1944

Diagnosis. — Three-dimensional burrow systems consisting predominantly of smooth-walled, essentially cylindrical components of variable diameter; branches Y- to T-shaped, enlarged at points of bifurcation (after Howard and Frey 1984).

Remarks. — *Thalassinoides* is produced by scavenging and deposit-feeder crustaceans (see Frey *et al.* 1984; Bromley 1996). It occurs in a great variety of environments, yet is most typical for the shelf *Cruziana* ichnofacies. For further discussion of this ichnogenus and its ichnotaxonomic problems see Fürsich (1973), Ekdale (1992) and Schlirf (2000).

Thalassinoides isp.
(Figs 5A, B, 6A–C, 7A, D, 8A–C)

Material. — Over 100 specimens and 4 filed photographs.

Description. — Horizontal, straight, slightly winding or rarely curved, unbranched or rarely branched, sub-cylindrical structures without walls, which are 28–110 mm wide (Fig. 6). The width can change in the same structure by about 10%. The collected fragments of the trace fossil are up to 31 cm long, but in the field at least 1 m long specimens have been observed. The surface is smooth or irregular due to weathering, or covered with indistinct, oblique, long, straight ridges arranged locally in a criss-cross pattern. In cross section, they form an irregular ellipse, which is 20–55 mm high and display a flattened bottom and distinctly arcuate top (Fig. 8B). In some of the specimens, the bottom is flat. The rare branches are Y-shaped (Figs 5B, 7D), rarely T-shaped.

Locally, the filling contains dispersed oval objects, which are 4–5 mm wide and up to 10 mm long (Fig. 9C). They are built of more fine-grained material than the surrounding rocks. Some of them display irregular, concentric structure.

Remarks. — Förster *et al.* (1987, pl. 43: 1) illustrated large sub-cylindrical, horizontal burrows and referred them to the associated crab *Antarctidromia inflata* Förster, 1985, of the superfamily Homolodromioidea. Birkenmajer (1995) identified these burrows as *Thalassinoides*. One specimen of the crab was found inside the burrow (see Fig. 7A).

Ichnogenus *Nereites* MacLeay, 1839

Diagnosis. — Usually selectively preserved, winding to regularly meandering, more or less horizontal trails, consisting of a median back-filled tunnel (core) enveloped by an even to lobate zone of reworked sediment (mantle). Commonly,

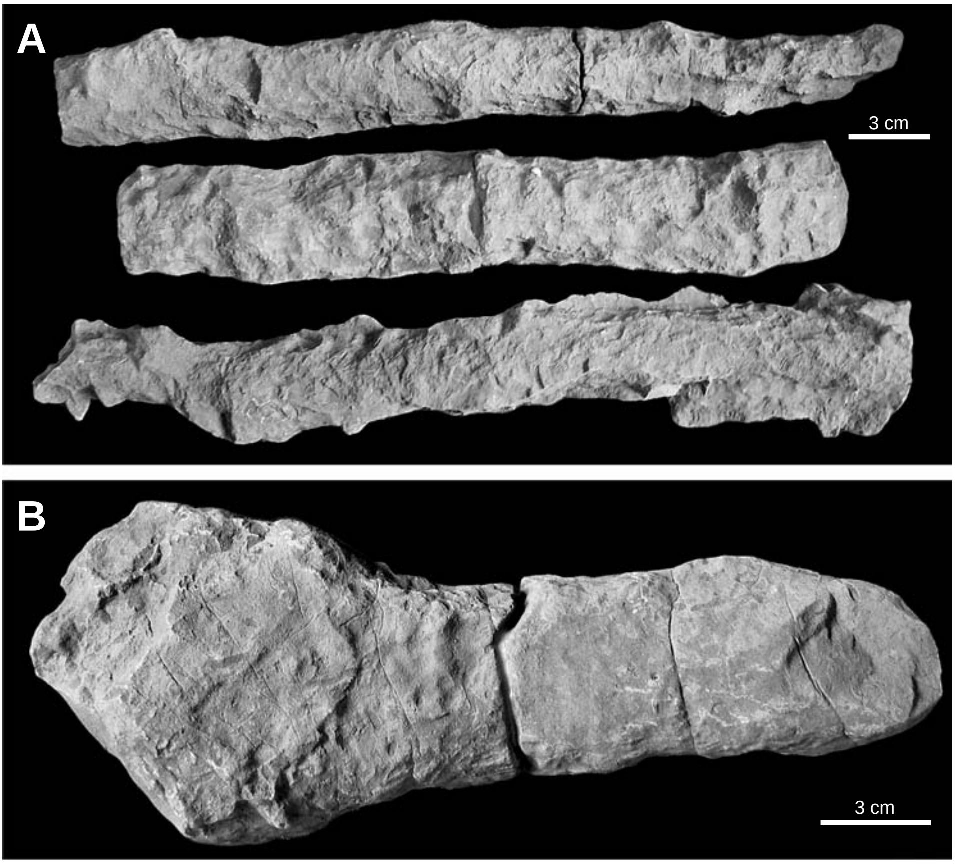

Fig. 5. *Thalassinoides* isp. **A**. Specimens (from the top to the bottom) ZPAL Tf.1/8, ZPAL Tf. 1/9, ZPAL Tf. 1/10. **B**. Specimen ZPAL Tf. 1/11. Cape Melville Formation (Lower Miocene), King George Island.

only the external part of the mantle is preserved as a densely packed chain of uni- or multi-serial small depressions or pustules (after Uchman 1995).

Remarks. — A list of ichnotaxa included in *Nereites* was presented by Rindsberg (1994) and Uchman (1995). *Nereites* was produced by pascichnial deposit feeders (Chamberlain 1971).

?*Nereites* isp.
(Figs 6B, 8D)

Description. — Meandering or looping endichnial ridges seen on horizontal parting surfaces, also in filling of *Thalassinoides*. The ridges are about 1 mm wide. The meanders are irregular, commonly curved. They are widened in the turning zone, where they are up to 5 mm wide. Their amplitude attains 20 mm. The looping ridges display common crossings at the same or slightly different levels. The ridges are more rare than the meandering ridges and they are up to 10 mm wide.

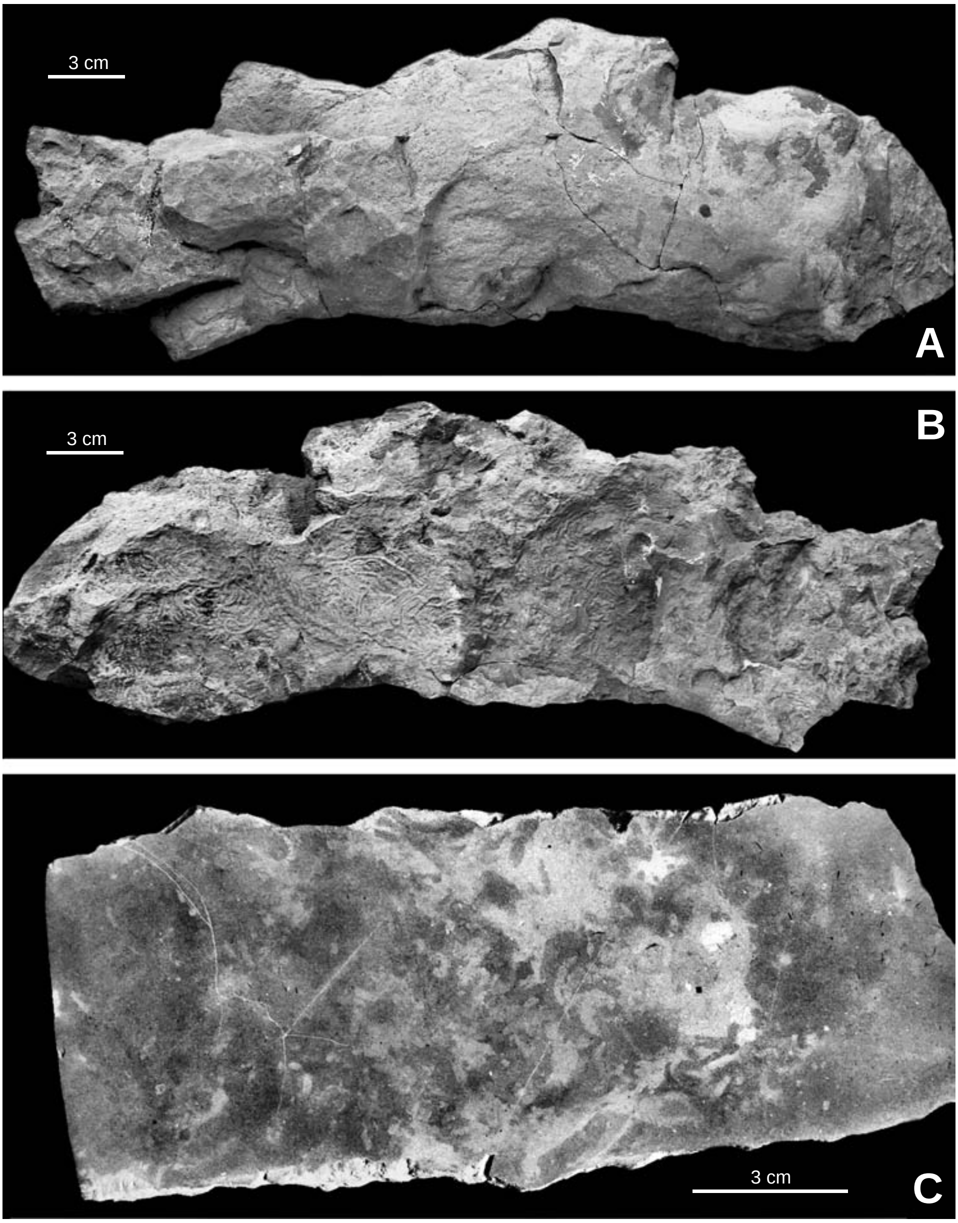

Fig. 6. *Thalassinoides* isp. **A**. Specimen ZPAL Tf. 1/12, top view. **B**. Specimen ZPAL Tf. 1/13, bottom view. The bottom is covered with ?*Nereites* isp. **C**. Polished filling of *Thalassinoides* isp. Note the bioturbational structures. Specimen ZPAL Tf. 1/14. Cape Melville Formation (Lower Miocene), King George Island.

Remarks. — The crossings are atypical of *Nereites* and the reworking zone is poorly outlined. Therefore the described trace fossil was only provisionally ascribed to *Nereites*.

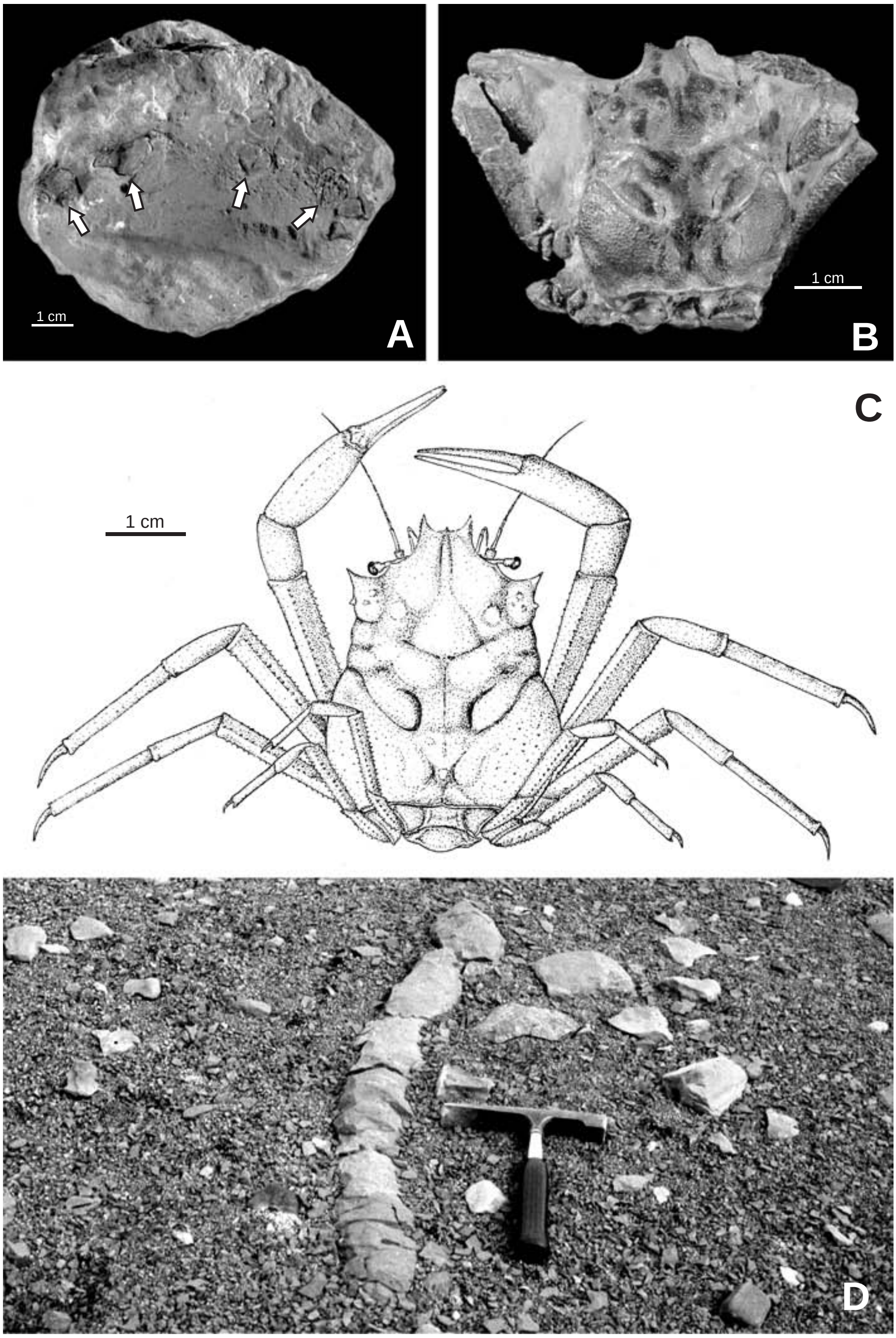

Fig. 7. **A**. Transversal section of "burrow" enclosing crab *Antarctidromia inflata* Förster in *Thalassinoides* isp. filling. Specimen ZPAL Cr. I/282. **B**. Crab *Antarctidromia inflata* Förster, 1985. Specimen ZPAL Cr. I/4, holotype. **C**. *Antarctidromia inflata* Förster, 1985, reconstruction. **D**. Branching *Thalassinoides* isp., field photograph. Cape Melville Formation (Lower Miocene), King George Island.

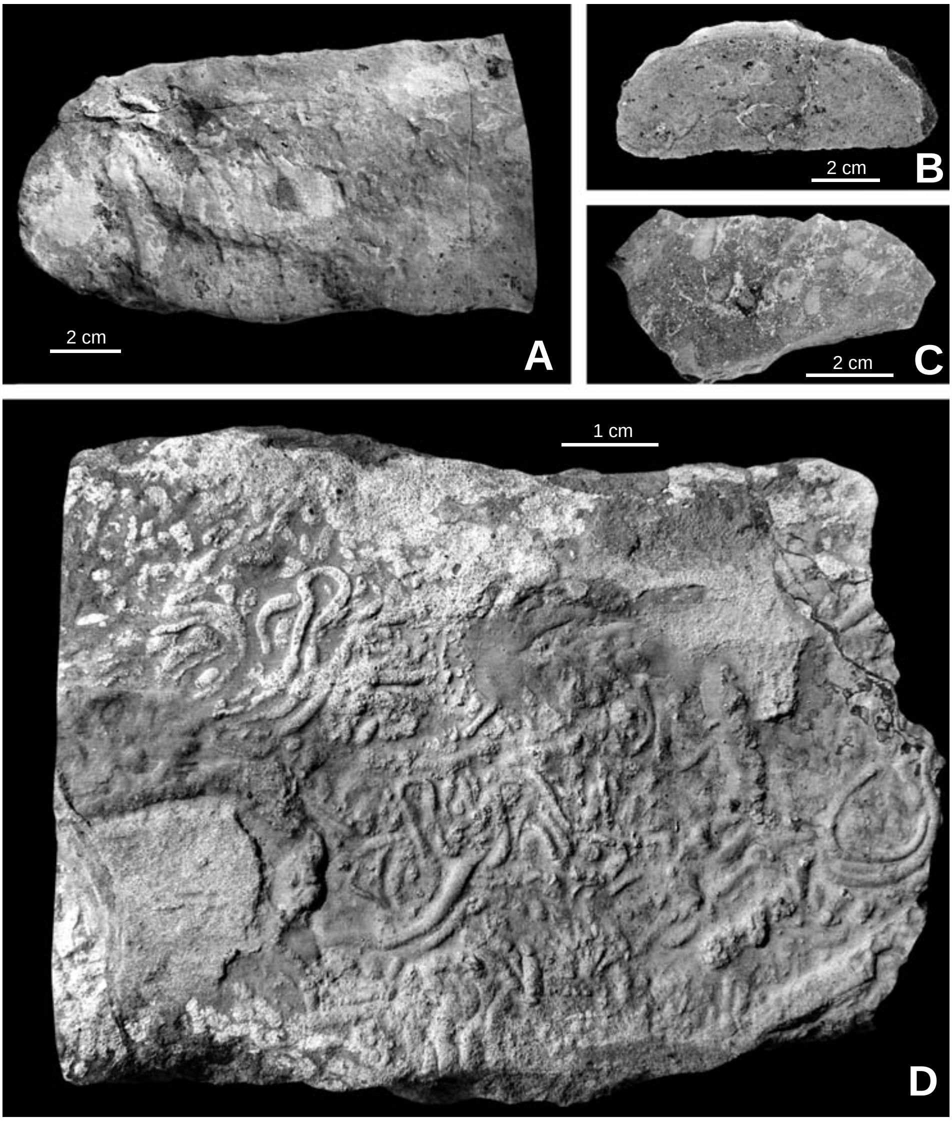

Fig. 8. Trace fossils and bioturbational structures from the Cape Melville Formation (Lower Miocene). **A**. *Thalassinoides* isp. Specimen ZPAL Tf . 1/ 15. **B**. Cross section of specimen ZPAL Tf. 1/16. Note the flattened bottom and arcuate roof. **C**. Bioturbational structures in filling of *Thalassinoides* isp. The oval objects can be faecal pellets. Specimen ZPAL Tf. 1/17. **D**. ?*Nereites* isp. on the bottom side of *Thalassinoides* isp. Specimen ZPAL Tf. 1/18.

Ichnogenus *Planolites* Nicholson, 1873

Diagnosis. — Unlined, rarely lined, rarely branched, straight to tortuous, smooth to irregularly walled or annulated trace fossils, circular to elliptical in cross-section, of variable dimensions and configurations: fill essentially structurless, differing in lithology from host rock (after Pemberton and Frey 1982, Fillion and Pickerill 1984).

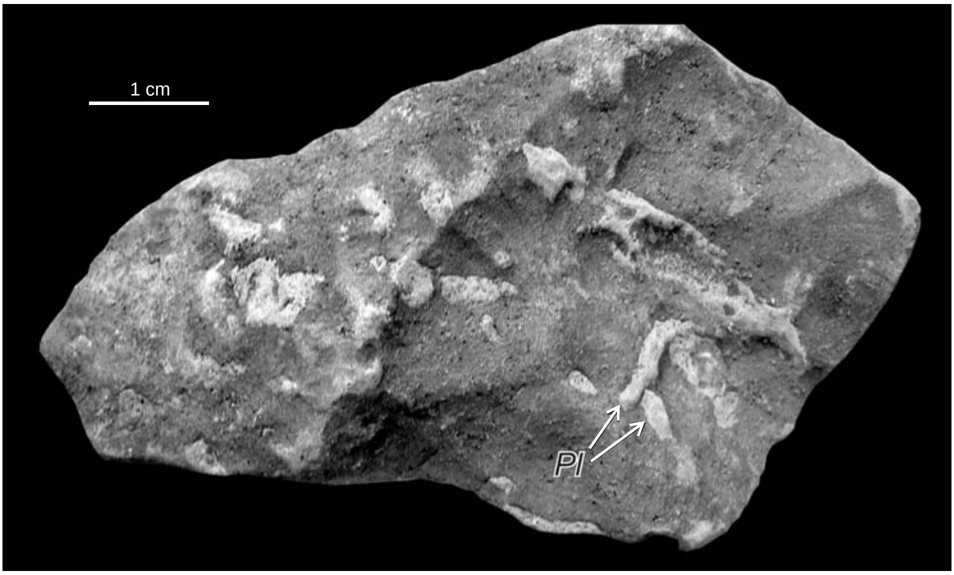

Fig. 9. *Planolites* isp. (*Pl*). Specimen ZPAL Tf. 1/19. Cape Melville Formation (Lower Miocene), King George Island.

Remarks. — Differences between *Planolites, Palaeophycus*, and *Macaronichnus* were discussed by Pemberton and Frey (1982), Fillion (1989), Fillion and Pickerill (1990), and Bromley (1996, p. 262).

Planolites is an eurybathic, extremely facies-crossing ichnogenus referred to polyphyletic vermiform deposit-feeders producing active backfilling (*e.g*. Pemberton and Frey 1982; Fillion and Pickerill 1990, and references therein).

Planolites isp.
(Fig. 9)

Material. — One specimen (ZPAL Tf. 1/19).

Description. — Horizontal to oblique tubular burrows without walls, 1.5–2 mm in diameter filled with slightly finer and lighter sediment than the host rock. The trace fossil is seen only in short segments.

Remarks. — Most probably, this trace fossil belong to *Planolites beverleyensis* Billings, 1862 (see Pemberton and Frey 1982) but the material is too poor for closer determination.

Discussion

Phymatoderma occurs mostly in outer shelf or deeper environments, including slope marls (*e.g*. Miller and Vokes 1998) and turbidites (Olivero *et al*. 2004, 2007; Ponce *et al*. 2004, 2007). Meandering ?*Nereites* isp. and strong sediment bioturbation (Figs 6C, 8C) also points to deeper environments. This confirms the interpretation of the crab, *Antarctidromia inflata* Förster, 1985, found in *Thalassinoides* isp. as a deep water animals (Förster *et al*. 1987). However, the large *Thalassinoides* could suggests shallower settings at least in the *Cruziana* ichnofacies, which is typical of offshore settings (Pemberton *et al*. 2001).

The presence of *Phymatoderma* with re-reworking of pelletal sediment suggests fluctuations in food supply (Miller and Vokes 1998; Miller and Aalto 1998). This fits very well with the marine glacial environment, where influx of melted waters caused fluctuations in food supply.

Finding of the crustacean tracemaker in its burrow is quite rare (see Neto de Carvalho *et al*. 2007 for review). *Antarctidromia inflata* Förster, 1985, found in *Thalassinoides* isp. is probably the first one in Antarctica (Förster *et al.* 1987). The second one comes from the Mount Discovery Formation (Lower–Middle Eocene), East Antarctica, where the callianassid *Callichirus*? *symmetricus* was found in *Ophiomorpha* (Stillwell *et al*. 1997; Schweitzer and Feldmann 2000).

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