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Early Cambrian molluscs from glacial erratics of King George Island, West Antarctica

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ABSTRACT: Molluscan fossils accompanied by familiar SSF have been recovered from Early Cambrian limestone erratics in the Early Miocene glaciomarine Cape Melville Formation of King George Island, West Antarctica. The molluscan fauna comprises the hyoliths *Conotheca*, *Microcornus*, *Parkula*, *Hyptiotheca*, "*Hyolithes*", the helcionelloids ?*Pararacornus*, *Yochelcionella*, *Anabarella*, the low dextrally coiled *Pelagiella* and the high helically coiled *Beshtashella*, as well as the problematic mollusc *Cupitheca*. Most of described species are recorded here for the first time from Antarctica. The lithological and fossil contents of the erratics are almost the same as from autochthonous successions the Shackleton Limestone in the Argentina Range and Transantarctic Mountains. Early Cambrian outcrops around the Weddell Sea are a probable source of the erratic boulders. The Antarctic fauna is very similar to that from uppermost Botomian and Toyonian carbonate deposits in the Cambrian Basins of South Australia. These faunal and facies similarities between Antarctica and Australia confirm their neighbouring position and common biotic and basin evolution on the Cambrian Gondwana margin.

Key words: Antarctica, King George Island, Cambrian, Hyolitha, Helcionelloida, Gondwana.

Introduction

The fossil assemblage recovered from Early Cambrian erratics derived from the Antarctica comprises abundant skeletal remains such as calcified cyanobacteria, archaeocyath and heteractinid sponges, lingulate brachiopods, ostracode and trilobite carapaces, and echinoderm ossicles, in addition to the molluscan fauna described herein. These are accompanied also by extremely abundant microscopic, originally phosphatic or secondarily phosphatized, small (usually less than 1–2 mm) fossils representing disarticulated exoskeletal sclerites, spines and various shells or tubes referred to as small skeletal fossils, abbreviated as SSF (Wrona 1989, 2004; Wrona and Zhuravlev 1996). Well-documented Cambrian shelly fossils have been described from many localities around the world (Fig. 4): Antarc-

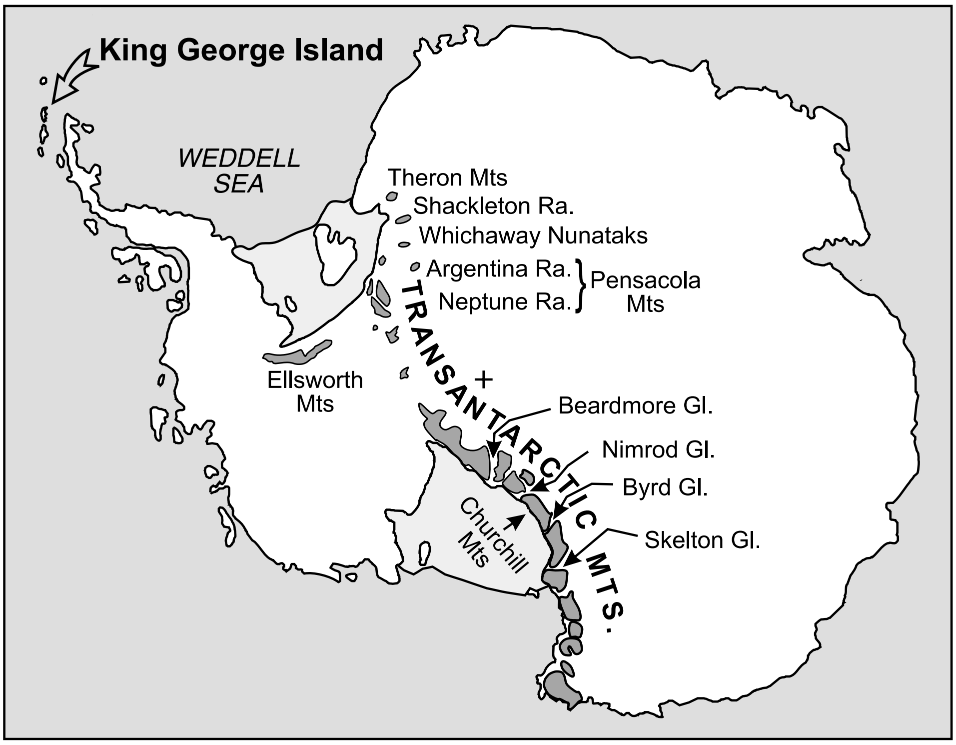

Fig. 1. Location map of King George Island (arrowed) and outcrops of Cambrian rocks (dark shaded) in Antarctica referred to in the text. Abbreviations: Mts = Mountains, Ra. = Range, Gl. = Glacier.

tica, Australia (Laurie 1986, Laurie and Shergold 1985, Bengtson *et al.* 1990, Hinz-Schallreuter 1993a; Kruse 1990, 1991, 1998; Brock *et al.* 2000, Gravestock *et al.* 2001) and Africa (Culver *et al.* 1988), North America (Conway Morris 1989, 1998; Landing 1988, Landing *et al.* 2002), China (Yin *et al.* 1980, Luo *et al*. 1982, He *et al.* 1984, Ding and Qian 1988, Qian and Bengtson 1989, Qian 1990), Europe (Poulsen 1967, Berg-Madsen and Peel 1978, Hinz 1987, Hinz-Schallreuter 1993b, Kerber 1988; Elicki 1994, 1998), Greenland (Peel 1991a, Conway Morris and Peel 1995), Kazakhstan (Missarzhevsky and Mambetov 1981), Mongolia (Esakova and Zhegallo 1996), and Siberia (Rozanov and Missarzhevsky 1966, Rozanov *et al.* 1969, Matthews and Missarzhevsky 1975, Missarzhevsky 1989, Rozanov and Zhuravlev 1992), but molluscan fossils from Early Cambrian deposits of Antarctica are still poorly known. Until recently, a scarce small skeletal fauna has been recorded from autochthonous Shackleton Limestone in the Churchill Mountains (Fig. 1B), the Holyoake Range between the Nimrod and Byrd Glaciers, and from the southeast of Mount Bowers (Rowell *et al.* 1988, Evans and Rowell 1990, Evans 1992), the Pensacola Mountains (Popov and Solovjev 1981, Rowell *et al.* 1992, Rode *et al.* 2003), and Early Cambrian boulders at Mount Provender,

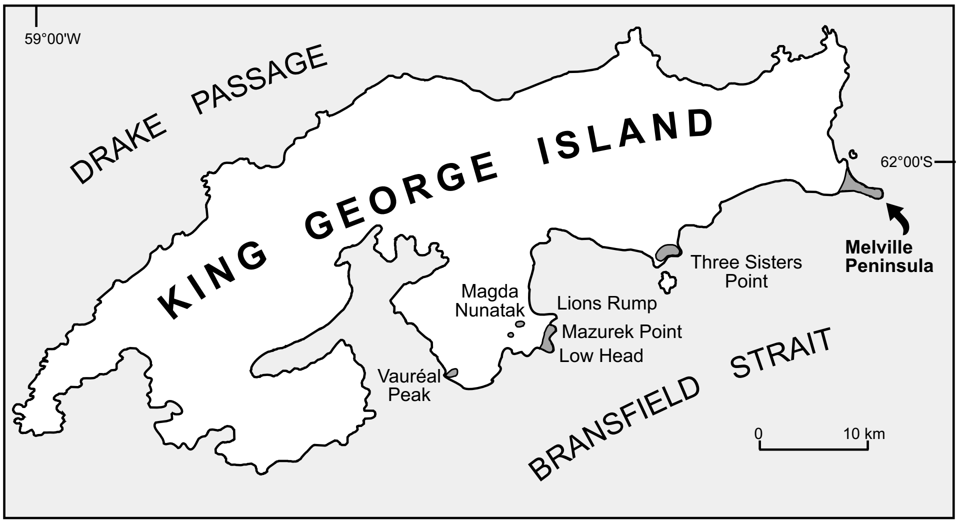

Fig. 2. The occurrence of Neogene glaciomarine strata (shaded) on King George Island and the collection site of the Early Miocene Cape Melville Formation (arrowed).

Shackleton Range (Clarkson *et al.* 1979). The Early Cambrian molluscan fauna described in this paper has been recovered from erratic boulders of limestone within the Early Miocene glaciomarine Cape Melville Formation of King George Island (Fig. 2), South Shetland Islands (Gaździcki and Wrona 1986; Wrona 1987, 1989, 2004).

This paper documents the micromolluscan fauna occurring in the Cambrian limestone erratics from King George Island. A complementary work concerning the accompanied small skeletal fossil assemblage is presented elsewhere (Wrona 2004).

Geographical and geological setting

Erratic boulders were sampled from Tertiary glaciomarine sediments of King George Island (South Shetlands) in West Antarctica (Fig. 1). The position of Tertiary rocks yielding erratic boulders is indicated on the map (Fig. 2). Erratics containing abundant Early Cambrian fossils were collected mainly from the Early Miocene Cape Melville Formation.

The Early Miocene glaciomarine Cape Melville Formation (CMF) is restricted to the easternmost part of King George Island, on Melville Peninsula (Fig. 2). The CMF sediments are exposed in northern and southern cliffs of the Melville Peninsula and on the ice-free surface of its flat plateau (Fig. 3). The local fossil assemblage of the CMF contains diatoms, chrysomonad (Gaździcki and Wrona 1986, Gaździcki 1989) and dinoflagellate cysts (Troedson and Riding 2002), silicoflagellates, calcareous and arenaceous foraminifers (Birkenmajer and Łuczkow-

Fig. 3. View of the Melville Peninsula plateau with erratic boulders as residual enrichment on the top of glaciomarine sediments of the Cape Melville Formation; Mount Melville, an extinct volcano, in background. Photographed in February 1981.

ska 1987), solitary corals (Roniewicz and Morycowa 1987), polychaetes (Szaniawski and Wrona 1987), bryozoans (Hara 1994), brachiopods (Bitner and Crame 2002), gastropods (Karczewski 1987), bivalves, decapods (Förster *et al.* 1985, 1987; Feldmann and Crame 1998), echinoids (Jesionek-Szamańska 1987), asteroids and fish remains of Miocene age, as well as reworked Cretaceous calcareous nannofossils and belemnites (Dudziak 1984, Birkenmajer *et al.* 1987). The age of the formation is determined by radiometrically (K-Ar) dated basalt lavas of the underlying Sherrat Bay Formation and transverse dikes, as well as by biostratigraphic studies, which indicate its deposition during the extensive earliest Miocene Glaciation in the Antarctic Peninsula region, the Melville Glaciation (Birkenmajer *et al.* 1983, 1984, 1985, 1987, 1989, 1992, 1995; Biernat *et al.* 1985, Dingle and Lavelle 1998, Gaździcki (ed.) 1987, Troedson and Riding 2002). The formation may represent glaciomarine deposits of regional marine-based grounded ice on the continental shelf and relatively ice-proximal up to ice-distal marine environment, with irregular input of coarse glacigenic debris from ice rafting (Troedson and Riding 2002).

Material and methods

The several hundred samples of fossil-bearing boulders were collected from glaciomarine sediments of the Early Miocene Cape Melville Formation of the

Melville Peninsula. Erratic boulders were at first studied for their petrography in thin sections and subsequently digested in acid. Phosphatic or phosphatized fossils were liberated using 10% acetic or formic acid. Selected fossils were prepared for scanning electron microscope examination. The sclerite wall microstructure was studied in broken or polished sections under transmitted light microscopy and scanning electron microscopy. Most of the figured stereoscan micrographs were taken using the Philips LX-20 scanning electron microscope at the SEM Laboratory of the Institute of Paleobiology, Warszawa. The studied collection of fossils is housed in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (abbreviated as ZPAL), and the collection is labelled as ZPAL V. XXVIII/1S10. The Arabic numerals immediately before the S indicate the number of the SEM stub and after the S, the specimen number on the stub (*e.g.* 1S10 means specimen no. 10 on the stub no. 1). The collection of the Antarctic erratics of King George Island housed in the Institute of Paleobiology, Warszawa is labelled: ZPAL AE/Me32, M33, and T52. The Arabic numerals indicate the number of the erratic sample (boulder) and the letters Me, M and T indicate their provenance of the Melville Peninsula, Mazurek Point and Three Sisters Point, respectively.

Lithology of erratic boulders

Allochthonous limestone boulders studied for their petrography were classified in three main lithological groups (see Wrona 1989, Wrona and Zhuravlev 1996).

Group 1: represented by dark packstone-wackestone and burrowed mudstone very rich in skeletal fossils (for detail see Wrona and Zhuravlev 1996). Stacked hyoliths, molluscs, bradoriids, lingulate shells (Holmer *et al.* 1996), echinoderm and trilobite fragments, coeloscleritophoran and palaeoscolecid sclerites, as well as sponge spicules are characteristic (Wrona and Zhuravlev 1996: pl. 1: 5, Wrona 2004). The shells are often filled with phosphatic material, which has produced internal moulds. Framboidal pyrite indicates sulphate-reduction, presumably because of the microbial activity in the sediment.

Group 2: represented by calcimicrobial-archaeocyathan reef limestone.

Group 3: bituminous dark-grey limestone with brachiopod shells and trilobite carapaces.

The black fossiliferous packstone-wackestones (Group I), calcimicrobial-archaeocyathan reef limestones (Group II) and bituminous dark-grey limestones with brachiopod shells and trilobite carapaces (Group III), correspond respectively to these of the Parara Limestone, Koolywurtie Limestone Member and Ramsay Limestone of the Yorke Peninsula (South Australia) succession (see Daily 1990, Zhuravlev and Gravestock 1994, Wrona and Zhuravlev 1996, Gravestock *et al.* 2001), as well as lithologies of the Shackleton Limestone of the central Transantarctic Mountains, Antarctic continent (Rees *et al.* 1989, Rowell and Rees 1989, Rowell *et al.* 1992). Some similarities also exist between these erratics and rocks from the Flinders Range (Arrowie Basin), in particular, the Mernmerna Formation, upper Wilkawillina Limestone and Wirrealpa Limestone, as well as the Tindall Limestone of the Daly Basin, Northern Territory (Fig. 4).

Fossil assemblage and the age of erratic boulders

The fossil assemblage from the limestone erratics includes archaeocyathan sponges (Wrona and Zhuravlev 1996), brachiopods (Holmer *et al.* 1996) and very rich small shelly fossils (Gaździcki and Wrona 1986; Wrona 1987, 1989, 2004). This assemblage is rich in juvenile biota (Holmer *et al.* 1996, Wrona 2004). The majority of skeletal fossils are preserved as phosphatic internal moulds of shells or as selective phosphatic replacements of the original $CaCO_3$ skeleton. Stacked, nested and variably oriented shells, especially brachiopod valves in coquinoid limestones, packstones and wackestones, exhibit a biofabric indicative of condensed deposits and reworked taphocenoses. This may be a result of very slow sedimentation and prolonged exposure of skeletal remains for destructive process. Their lithology and palaeontological contents suggest that they represent sediments of a relatively deep marine environment with oscillating anaerobic, dysaerobic and aerobic bottom conditions (Wrona and Zhuravlev 1996). The Early Cambrian phosphatized SSF assemblages of Antarctica are similar to other small shelly fossil assemblages that appeared at the beginning of the Cambrian, and reoccurred several times throughout the Early Paleozoic (Dzik 1994a, b). It has been argued that the repeated global appearance of these fossils resulted from an extinguishing of benthic environments (Dzik 1994a, Zhuravlev and Wood 1996), and probably a vast event of Early Cambrian phosphogenesis (Cook and Shergold 1984, 1986; Brasier 1990).

Three distinct faunal assemblages are recognized in the Early Cambrian fossils from the King George Island (Wrona and Zhuravlev 1996, Wrona 2004):

(1) A very rich and diverse SSF assemblage with sponge spicules. Molluscs are represented by the helcionellids ?*Pararaconus* cf. *staitorum* Runnegar in Bengtson *et al.*, 1990 (Fig. 12A–C), *Yochelcionella* sp. (Fig. 13A), *Anabarella* cf. *argus* Runnegar in Bengtson *et al.*, 1990 (Fig. 13B), and *Pelagiella madianensis* (Zhou and Xiao, 1984) (Fig. 13C–E), and the helically coiled *Beshtashella tortilis* Missarzhevsky, 1981 (Fig. 14A–E), the hyoliths *Conotheca australensis* Bengtson in Bengtson *et al.*, 1990 (Fig. 5A–E), *Microcornus petilus* Bengtson in Bengtson *et al.*, 1990 (Fig. 8A–H), *Parkula bounites* Bengtson in Bengtson *et al.*, 1990 (Fig. 5F), *Hyptiotheca carraculum* Bengtson in Bengtson *et al.*, 1990 (Figs 9A–B, 10A–E), and "*Hyolithes*" *conularioides* Tate, 1892 (Fig. 11G), and the hyolith-like fossil *Cupitheca holocyclata* (Bengtson in Bengtson *et al.*, 1990) (Figs

11A–F, G_3). Arthropods are represented by the bradoriid *Albrunnicola bengtsoni* Hinz-Schallreuter, 1993b conspecific with *Hipponicharion* sp. from the Parara Limestone of Yorke Peninsula, South Australia (Bengtson *et al.* 1990: 325, fig. 207A). The problematic tommotiids are represented by *Dailyatia ajax* Bischoff, 1976, *Lapworthella fasciculata* Conway Morris and Bengtson in Bengtson *et al.*, 1990, and the tommotiid new genus and species (see Wrona 2004). The coeloscleritophorans include the chancelloriids *Ch. racemifundis* Bengtson in Bengtson *et al.*, 1990, *Allonnia* ex gr. *tripodophora*, *A.* cf. *tetrathallis*, and *Archiasterella*? sp., and the halkieriid *Halkieria parva* Conway Morris in Bengtson *et al.*, 1990. Tubes are diverse and represent *Hyolithellus filiformis* Bengtson, 1990 in Bengtson *et al.* 1990, *H. micans* (Billings, 1871), *Torellella* sp. and *Byronia*? sp. nov. In addition, trilobite fragments, archaeocyath internal moulds, ?radiocyathid nesasters, palaeoscolecid sclerites and spines of *Mongolitubulus* Missarzhevsky, 1977 are present. The problematic microfossil *Aetholicopalla adnata* Conway Morris, 1990 in Bengtson *et al.* 1990 occurs in the studied Early Cambrian Antarctic erratics and the Parara Limestone of Yorke Peninsula, South Australia (Bengtson *et al.* 1990, Gravestock *et al.* 2001), and the Marianian strata (?uppermost Atdabanian–Botomian) of Görlitz Syncline, Central Europe (Elicki and Schneider 1992, Elicki 1998).

The absence of typical late Atdabanian fossils suggests a lower age limit of the fossil assemblage within the *Pararaia tatei* trilobite Zone (Bengtson *et al.* 1990) or *Halkieria parva* SSF “Zone” (Gravestock *et al.* 2001); a lower Botomian age is the most plausible because many King George Island fossils are not known from later deposits (Bengtson *et al.* 1990, Zhuravlev and Gravestock 1994, Wrona and Zhuravlev 1996, Gravestock *et al.* 2001, Wrona 2004). This assemblage is closely similar to late Atdabanian-early Botomian Australian assemblages, especially that from the Stansbury Basin, Parara Limestone of Yorke Peninsula.

(2) An assemblage with reef organisms represented by archaeocyaths, coralomorphs and calcified cyanobacteria described by Wrona and Zhuravlev (1996). All studied erratics contain common elements with the *Syringocnema favus* beds assemblage of South Australia which is correlated by Zhuravlev and Gravestock (1994) with the late Botomian. Moreover, similar elements have been identified in the King George Island erratics from the Polonez Cove Formation (Morycowa *et al.* 1982, Debrenne and Kruse 1986). Of the total of 52 archaeocyath species known from Antarctica, 60% are in common with Australia (Wrona and Zhuravlev 1996).

(3) An assemblage with lingulate brachiopod shells (Holmer *et al.* 1996), accompanied by sponge spicules, chancelloriid sclerites, shells of the mollusc *Pelagiella madianensis* (Zhou and Xiao, 1984) (Fig. 13C–E), hyolith conchs, trilobite carapaces and palaeoscolecid sclerites. The brachiopods *Eoobolus* aff. *E. elatus* (Pelman, 1986), *Karathele napuru* (Kruse, 1990), and *Vandalotreta djagoran* (Kruse, 1990) are similar to assemblages described from the Toyonian Wirre-

alpa Limestone of the Flinders Ranges, and Ramsay Limestone of Yorke Peninsula, South Australia, and the Tindall Limestone of the Daly Basin (Fig. 4), Montejinni Limestone of the Wiso Basin and Gum Ridge Formation of the Georgina Basin, Northern Territory (Kruse 1990, 1998; Brock and Cooper 1993, Holmer *et al.* 1996, Gravestock *et al.* 2001, see also Fig. 4). Moreover, *K. napuru* and *V. djagoran* are also known from the Top Springs Limestone of the northern Georgina Basin, Northern Territory (Kruse 1991). The palaeoscolecid sclerite *Hadimopanella antarctica* Wrona, 1987 resembles, in size and ornamentation, the Australian coniform sclerite of *Chalasiocranos exquisitum* Brock and Cooper, 1993 from the Ramsay Limestone of Yorke Peninsula (Brock and Cooper 1993, Wrona 2004). The disarticulated sclerites of *Hadimopanella* sp. nov. (Wrona 2004) represent other components of this assemblage and are similar to the microplate of *Kaimenella dailyi* Brock and Cooper, 1993.

This assemblage in general belongs to the middle Toyonian *Archaeocyathus abacus* beds, correlated with the molluscan *Pelagiella madianensis* and SSF *Kaimenella reticulata* “zones” (Zhuravlev and Gravestock 1994, Gravestock *et al.* 2001).

Comparison

The comparisons of the Australian and Antarctic Early Cambrian fossil assemblages are based on the monographic studies of skeletal fossils from Australia (Daily 1956, Bengtson *et al.* 1990, Brock and Cooper 1993, Brock *et al.* 2000, Gravestock *et al.* 2001) and from Antarctica (Wrona 1987, 1989, 2004; Evans and Rowell 1990, Cooper and Shergold 1991, Holmer *et al.* 1996, Rode *et al.* 2003, Wrona and Zhuravlev 1996). The present molluscan fauna from allochthonous blocks of King George Island attests to a close relationship at the species level with molluscan fauna from the Arrowie Basin, Ajax Limestone of Flinders Ranges and Stansbury Basin, Parara Limestone of Yorke Peninsula in South Australia (Daily 1990, Runnegar 1983, Runnegar in Bengtson *et al.* 1990, Brock and Copper 1993, Brock *et al.* 2000, Gravestock *et al*. 2001). The closest similarities occur with the remote Arrowie and Stansbury Basins of South Australia (Figs 1, 4), and are consistent with the similarities observed between analogous archaeocyatan faunas (Wrona and Zhuravlev 1996). The most possible explanations are, that both basins, especially the Stansbury Basin, were Australian basins proximal to the continuous East Antarctic shelf along which the fauna freely migrated (Fig. 4), or that the several more or less isolated basins might have existed along Australian and Antarctic parts of the East Gondwana margin (Wrona and Zhuravlev 1996). Those basins might have been connected only during the most prominent transgressions, thus allowing faunal exchange. In fact, transgressive tracts were suggested for early Botomian, late Botomian and middle Toyonian times based on the sequence

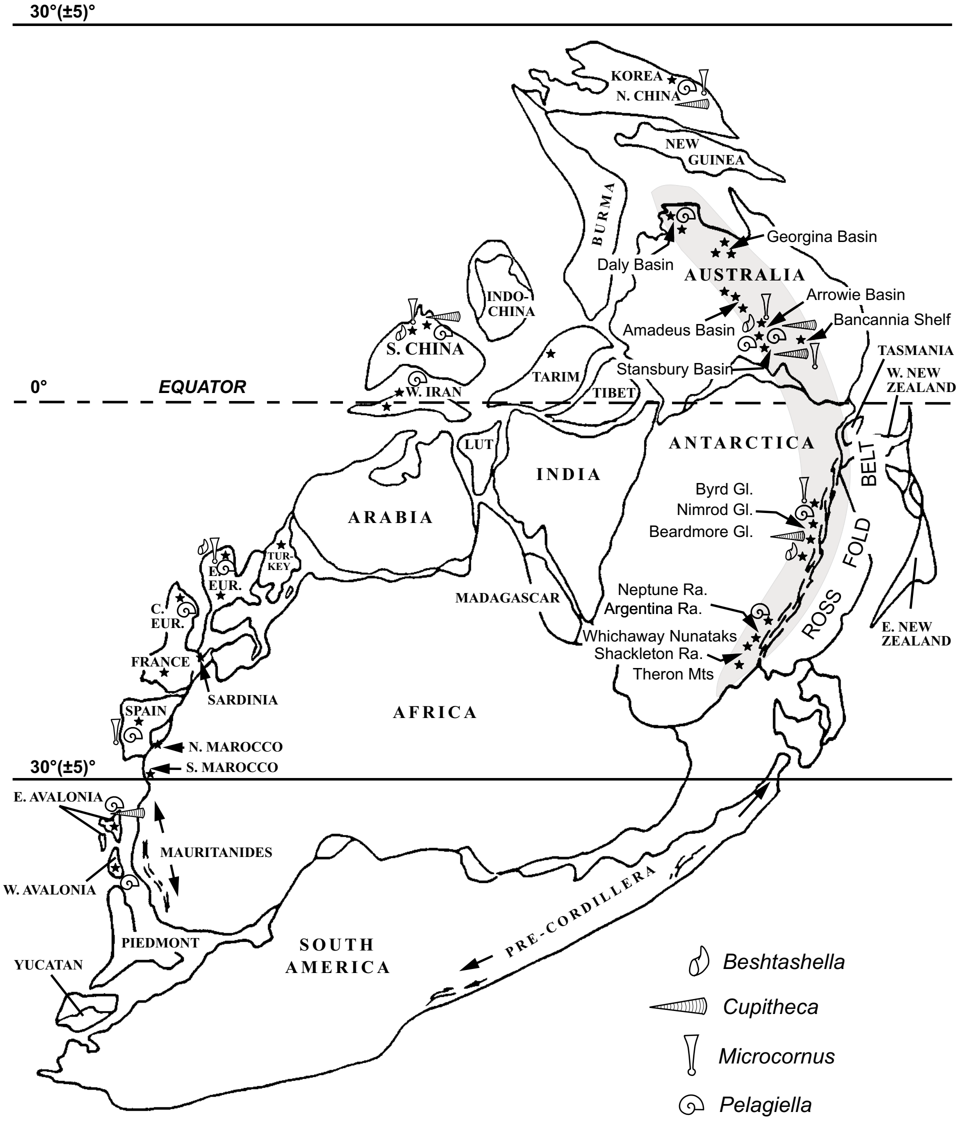

Fig. 4. Early Cambrian palaeogeograpic map with the major sedimentary basins of Australia and Antarctica discussed in the text (modified after Courjault-Radé *et al.* 1992). Asterisks show distribution of the most important small skeletal fossil occurrences, and distribution of selected genera are marked with icons. References for distribution data are in the text and are modified partly after Brock *et al.* 2000.

stratigraphy of South Australian basins (Gravestock *et al.* 2001, Gravestock and Hibburt 1991, Gravestock and Shergold 2001). Many species common for Antarctica and Australia, but originally documented only from Australia, now known from Early Cambrian localities in many parts of the world and become useful for global biostratigraphic and palaeogeographic correlation (Brock *et al.* 2000). At the generic level (*Conotheca*, *Microcornus*, "*Hyolithes*", ?*Pararacornus*, *Yochelcionella*, *Anabarella, Pelagiella*, and *Beshtashella*), the Antarctic Early Cambrian molluscs show close relationships with equivalent assemblages from Australia, North America, South and North China, Europe, Greenland, Iran, Kazakhstan, Mongolia, Tien Shan, Siberia, eastern Laurentia, and Avalonia.

Provenance of limestone erratic boulders

The erratics in shales of the Cape Melville Formation, interpreted as ice-rafted dropstones, were delivered to the Early Miocene basin by drifting icebergs derived from the margin of Antarctic ice shelves, and transported by sea surface currents (Wrona 1989, Troedson and Riding 2002). The erratic boulders are mainly igneous, metamorphic, or siliciclastic rocks, whereas limestones account for some 5% of the total number of boulders (Wrona 1989, Wrona and Zhuravlev 1996). Petrographic features of these rocks point to source areas on the Antarctic continent (Morycowa *et al.* 1982, Wrona 1989, Wrona and Zhuravlev 1996). However, only three Antarctic occurrences containing small shelly fossils are known. These are the autochthonous Shackleton Limestone in the Churchill Mountains between Nimrod and Byrd Glaciers and in the southeast of Mount Bowers (Rowell *et al.* 1988, Evans and Rowell 1990, Evans 1992, Palmer and Rowell 1995), the upper Lower Cambrian (Botomian) of the Pansacola Mountains (Popov and Solovjev 1981, Rode *et al.* 2003), and Lower Cambrian allochthonous boulders at Mount Provender, Shackleton Range yielding molluscs compared with *Helcionella* and *Mellopegma* by Clarkson *et al.* (1979). No one contains species in common with the King George Island erratics. It is likely that strata bearing small shelly fossils are presently covered by the Antarctic continental ice-sheet. However, the entire lithological composition of a whole spectrum of erratics from the CMF clearly suggest that Lower Cambrian bedrocks around the Weddell Sea (in particular the Argentina Range in Pensacola Mts) and northern Transantarctic Mts acted as parent rocks for the glacial boulders. Namely, Birkenmajer (1980; 1982a, b) and Birkenmajer and Butkiewicz (1988) suggested that the main sources of the igneous erratics of King George Island might be: Antarctic Peninsula, Ellsworth Mountains, Pensacola and Theron Mountains, which provide the entire diversity of igneous and metamorphic dropstone lithologies. Wrona and Zhuravlev (1996) suggested that the archaeocyath-bearing erratics collected, together with SSF-bearing erratics, from glacigenic deposits of King George Island have been derived mainly from locations along the Weddell Sea coast and from the Transantarctic Mts. The archaeocyath-bearing limestone occurring in the Ross Orogen, at least between Nimrod Glacier and the Theron Mountains (Debrenne and Kruse 1986, 1989), could be the source area for erratics of this lithologic group. The Argentina Range (in Pensacola Mts) is the locality (Fig. 1) nearest to King George Island with *in situ* archaeocyaths (Konyushkov and Shulyatin 1980).

Systematic palaeontology

Phylum Mollusca Cuvier, 1797
Class Hyolitha Marek, 1963

Remarks. — Despite significant advances in the understanding the hyoliths architecture and palaeobiology (*e.g.* Marek 1966, Runnegar *et al.* 1975, Marek and Yochelson 1976, Dzik 1978, 1980; Kruse1997) their taxonomy and systematic relationships are still under discussion (Marek and Yochelson 1976, Runnegar *et al.* 1975, Meshkova 1974, Runnegar 1980, Val'kov *et al.* 1983, Yochelson 1987, Malinky 1990, Dzik 1994b; Kruse1990, 1998). I find the arguments to maintain hyoliths within the phylum Mollusca (Marek and Yochelson 1964, 1976; Dzik 1979, 1994b) convincing.

Order Orthothecida Marek, 1966
Family Circothecidae Missarzhevsky in Rozanov *et al.*, 1969
Genus *Conotheca* Missarzhevsky in Rozanov *et al.*, 1969

Type species: *Conotheca mammilata* Missarzhevsky in Rozanov *et al.*, 1969.

Conotheca cf. *C. australiensis* Bengtson in Bengtson *et al.*, 1990
(Fig. 5A–E)

Material. — Four phosphatized opercula and seven conch internal moulds with the operculum in place, ZPAL V.VI/52U1, 19U8 from erratic boulders Me32, 33 and 66.

Description. — Circular, phosphatized operculum. The external side is convex and covered with concentric growth lines. The external surface is partly exfoliated, and exhibits internal growth structure and prominent growth centre. The internal side has a characteristic marginal zone in the form of a regular brim. Two cardinal processes are partly broken and diverge at about 30°. Conch internal moulds are not complete, about 2.5 mm long, gently curved, with smooth surface, and circular cross-section.

Remarks. — Internal moulds resemble *Conotheca australiensis* Bengtson, 1990 (in Bengtson *et al.* 1990) internal moulds, but are more gently curved; they lack the initial (the proximal?) end. The operculum has cardinal processes which are less closely spaced than in the Australian type material. Lateral pairs of clavicle-like tubules on the internal margin, distinctive for the species, have not been observed because of the missing lower-central portion of the operculum. Conch and operculum were primarily calcitic and in acid residues usually occur as deeply

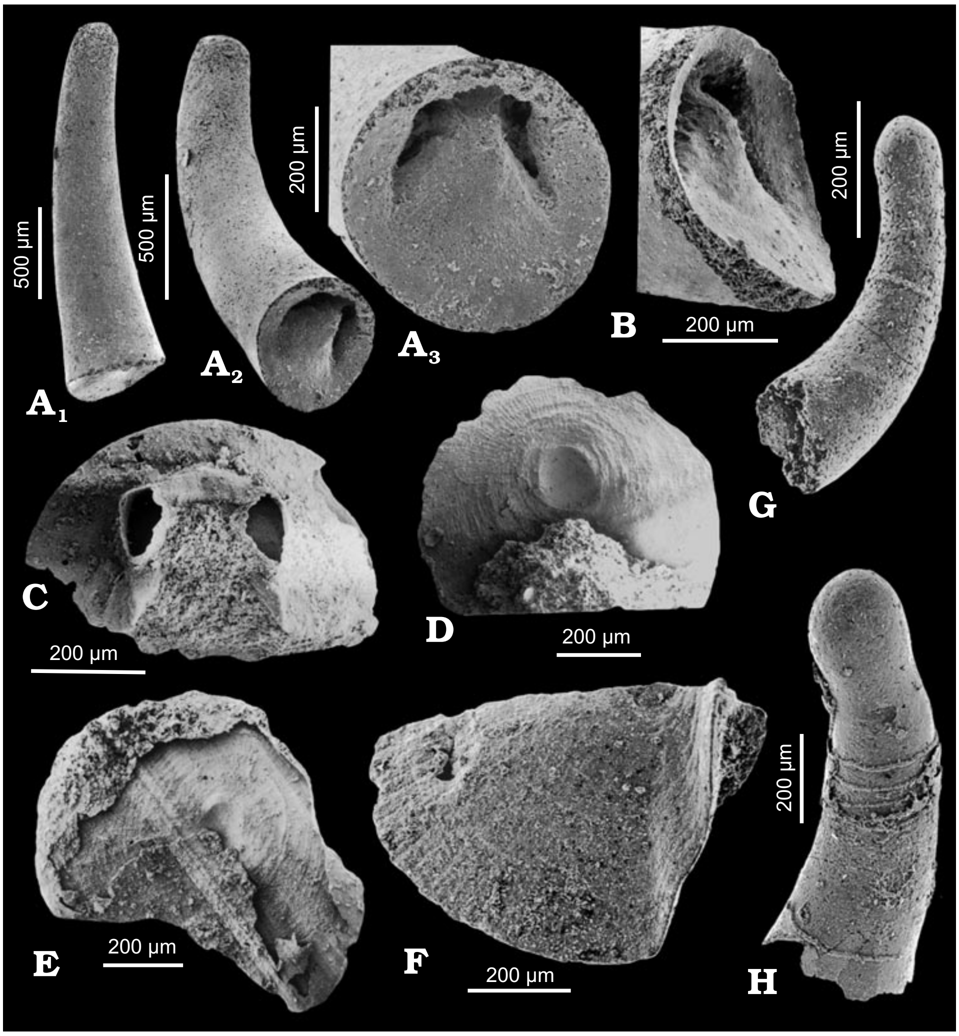

Fig. 5. **A**–**E**. *Conotheca* cf. *australiensis* Bengtson. **A$_1$**. Internal mould of conch in lateral view, ZPAL V.VI/52U1, erratic Me66. **A$_2$**. The same in oblique ventrolateral view. **A$_3$**. Apertural view, note operculum in place. **B**. Internal mould of apertural part of conch, with in-place operculum, in lateral view (dorsum at top), ZPAL V.VI/19U8, erratic Me33. **C**. Damaged operculum in internal view, ZPAL V.VI/32S8, erratic Me66. **D**. Operculum, broken and slightly covered with mineral matter and removed external wall layer, in external view, ZPAL V.VI/32S1, erratic Me66. **E**. Broken operculum with external wall layer partly removed, in external view, ZPAL V.VI/28S16, erratic Me66. **F**. Operculum of *Parkula bounites* Bengtson, external side in oblique lateral view (dorsum at top), ZPAL V.VI/103S3, erratic Me66. **G**–**H**. *Conotheca* sp. A. **G**. Internal mould of conch in lateral view, ZPAL V.VI/106S7, erratic Me66. **H**. Internal mould of conch coated with fragment of the shell, in lateral view, ZPAL V.VI/115S2, erratic Me66.

phospatized shell or internal moulds. Consequently, a more precise designation of the Antarctic specimens is not possible at present.

Conotheca sp. A
(Fig. 5G–H)

Material. — Seven internal moulds of conchs, often with operculum in place or internal mould of a loose operculum, ZPAL V.VI/106S7l; 115S2; from erratic boulders Me32, 66.

Description. — Moderately tapering conch, with slightly bulbous apex. Conch gently curved aperturally. The internal mould is circular to subcircular in cross-section. The surface is smooth, indicating that the conch inner surface is also smooth. Conch primarily calcitic and in acid residues usually occurring as a phosphatic internal mould (Fig. 5G–H).

Conotheca sp. B
(Fig. 6A–F)

Material. — Twelve internal moulds of conchs, often with operculum preserved in situ or internal mould of a loose operculum, ZPAL V.VI/52S4, 103S6, 7, 8; 109S1, 2; 112S1; from erratic boulders Me32, 33, 66.

Description. — Moderately tapering conch, with slightly bulbous apex. Conch curved in the initial part and straight or less curved aperturally. The internal mould is subcircular in cross-section, with ventral side flattened. Its surface is smooth, as was the conch inner surface. Conch primarily calcitic and in acid residues usually occuring as a phosphatic internal mould.

Remarks. — The incomplete conch and poorly preserved internal moulds, often with the operculum in place, are insufficient for a complete description. The internal moulds are partly etched, but even loose opercula with characteristic shape and sculpture (Fig. 6C–D), possibly belongs to the conch of *Conotheca* sp. B.

Order Hyolithida Matthew, 1899
Genus *Microcornus* Mambetov, 1972

Type species: *Microcornus parvulus* Mambetov, 1972.

?*Microcornus* ex gr. *M. eximius* Duan, 1984
(Fig. 7A–C)

Material. — A dozen internal moulds, ZPAL V.VI/112S2, 3, 9, from erratic boulders Me33, 66.

Description. — Conch strongly tapering, straight, with angle of divergence 25° increasing to 30° towards the flared aperture. The apex was not observed. Transverse section of conch is rounded-triangular. Ventral side flat to gently convex, lateral sides rounded, and dorsal side has a distinct rounded median ridge. Internal moulds have a smooth surface, reflecting the smooth inner surface of the conch. Conch primarily calcitic and in acid residues usually occurring as a phosphatic internal mould.

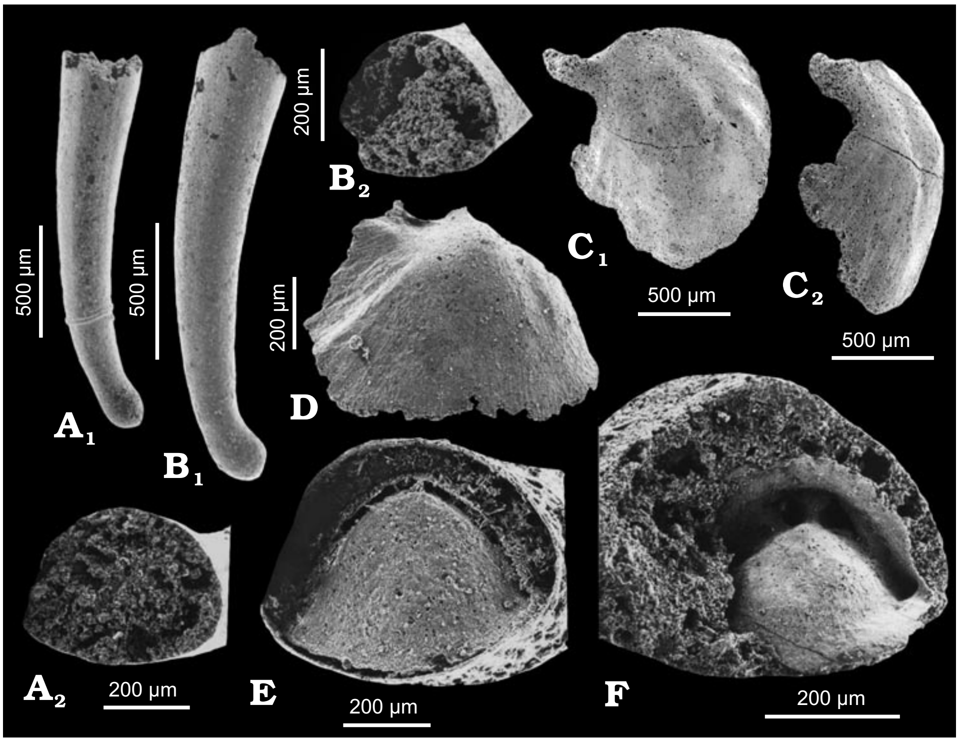

Fig. 6. **A**–**F**. *Conotheca* sp. B. **A$_1$**. Internal mould of conch in lateral view, ZPAL V.VI/112S1, erratic Me66. **A$_2$**. Same in apertural view. **B$_1$**. Internal mould of conch in lateral view, ZPAL V.VI/109S1, erratic Me66. **B$_2$**. Same, in apertural view, note week trace of in-place operculum. **C$_1$**. Internal mould of hyolith operculum (?*Conotheca* sp.) in oblique view, ZPAL V.VI/52S4, erratic Me33. **C$_2$**. The same in oblique lateral view. **D**. Broken internal mould of operculum, in external view, ZPAL V.VI/103S7, erratic Me66. **E**. Shell internal mould with operculum in place, partly etched, in apertural view ZPAL V.VI/109S1, erratic Me33. **F**. Conch steikern in apertural view, note operculum in place, ZPAL V.VI/103S8, erratic Me33.

Remarks. — The poorly preserved internal moulds with the missing initial ends are insufficient for a complete description. Some more completely preserved internal moulds of simple morphology can be compared to the conchs of the indeterminate hyolithide recorded by Kruse (1990: fig. 22), from the Middle Cambrian of the Daly Basin, Northern Territory, Australia.

Microcornus petilus Bengtson in Bengtson *et al.*, 1990
(Fig. 8A–H)

Microcornus petilus sp. nov.; Bengtson, 1990 in Bengtson *et al.* 1990: 217, figs 145–147.

Microcornus petilus Bengtson in Bengtson *et al.*; Demidenko in Gravestock *et al.* 2001: 99, pl. 10: 10.

Material. — A number of internal moulds, ZPAL V.VI/34S22, 35S9; 106S6; 108S8; 110S4, 5; 114S4; 115S6; from erratic boulders Me32, 33, 66.

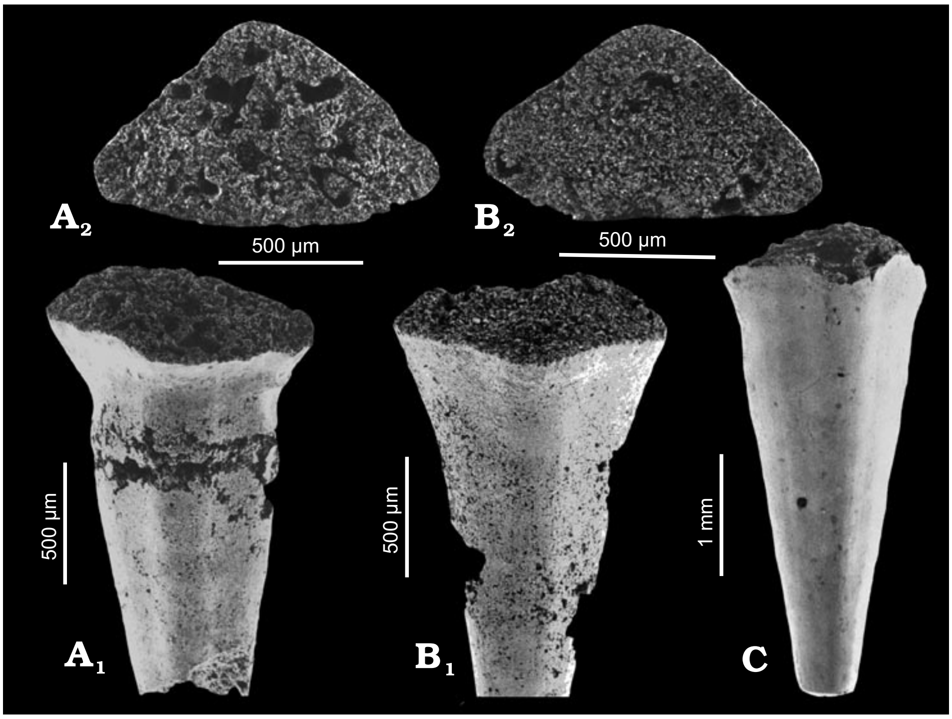

Fig. 7. **A**–**C**. *Microcornus* ex gr. *M. eximius* Duan. **A$_1$**. Conch internal mould, dorsum, ZPAL V.VI/112S9, erratic Me66. **A$_2$**. The same in apertural view (dorsum at top). **B$_1$**. Seainkern of conch, dorsum, ZPAL V.V/I112S2, erratic Me66. **B$_2$**. The same in apertural view (dorsum at top). **C**. Internal mould of conch, dorsum, ZPAL V.VI/112S3, erratic Me66.

Description. — Straight conch up to 3 mm long, usually less, rounded-triangular in cross-section, with dorsal median ridge, and dorsal side more convex than ventral (Fig. 8B$_2$, H). Conch slender conoidal, with angle of divergence about 15° to 20°. Ligula not observed. Outer surface of internal moulds smooth, reflecting the smooth inner surface of the conch. Initial part of conch bulbous. Conch primarily calcitic; in acid residues usually occurring only when phosphatized and as a phosphatic internal mould. Operculum not observed.

Occurrence. — Early Cambrian (Atdabanian/Botomian) Kulpara Formation and Parara Limestone, Horse Gully, Yorke Peninsula, Stansbury Basin, South Australia; King George Island, Antarctica.

Microcornus cf. *M. petilus* Bengtson in Bengtson *et al.*, 1990
(Fig. 8I–J)

Material. — Ten internal moulds, ZPAL V.VI/27S4, 34S17 from erratic boulders Me33, 66, 110.

Description. — Slender conch up to 2 mm long, straight or gently curved and rounded-triangular to subelliptical in cross-section. Outer surface without trace

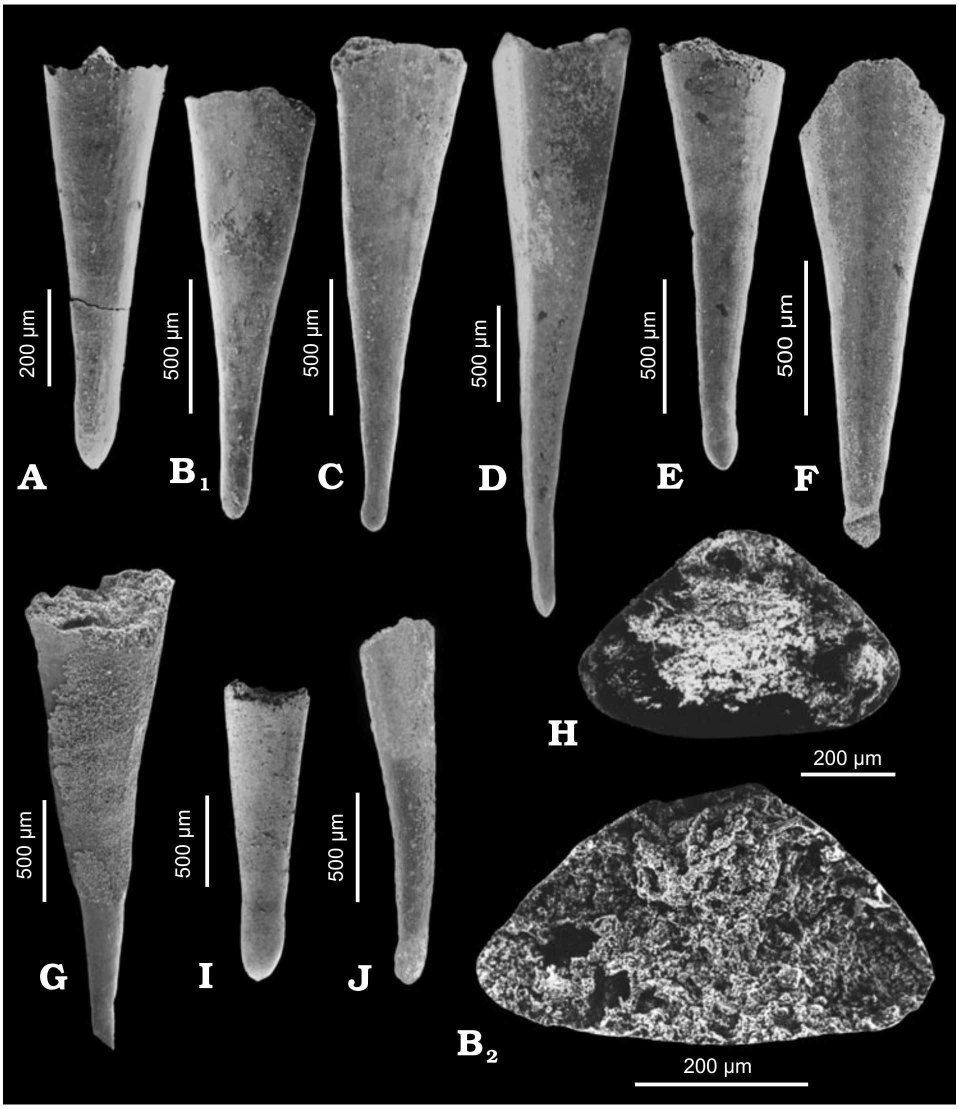

Fig. 8. **A**–**H**. *Microcornus petilus* Bengtson. **A**. Conch internal mould, view of dorsum, ZPAL V.VI/34S22, erratic Me32. **B$_1$**. Conch internal mould, viewof venter, ZPAL V.VI/110S5, erratic Me66. **B$_2$**. Apertural view of conch, dorsum at top. **C**. Conch internal mould, view of venter, ZPAL V.VI108/S8, erratic Me32. **D**. Conch internal mould, view of dorsum, ZPAL V.VI/114S4, erratic Me33. **E**. Internal mould of conch, viewof dorsum, ZPAL V.VI/115S6, erratic Me66. **F**. Conch internal mould, view of venter, ZPAL V.VI/106S6, erratic Me66. **G**. Conch internal mould, view of ventrum, ZPAL V.VI/35S9, erratic Me32. **H**. Internal mould of conch in apertural view, dorsum at top, ZPAL V.VI/110S4, erratic Me66. **I**–**J**. *Microcornus* cf. *petilus* Bengtson. **I**. Internal mould of conch, view of dorsum, ZPAL V.VI/34S17, erratic Me33. **J**. Internal mould of conch in lateral view, dorsum to left, ZPAL V.VI/27S4, erratic Me110.

surface sculpture. Longitudinal ribs at dorsoventral margins and logitudinal keels at the dorsum were not observed. Inner surface of conch is therefore smooth. Conch usually gently tapering apically. Conch primarily calcitic and in acid residues usually occurring as a more or less complete phosphatic internal mould. Operculum not observed.

Remarks. — All available specimens are internal moulds which are too poorly preserved for a more complete description, however they differ from the *M. petilus* type species (Bengtson in Bengtson *et al.* 1990), and from the somewhat similar internal moulds of linevitide conchs (for example *Linevitus* Sysoev, 1958)) in lacking longitudinal keels on the dorsum.

Genus *Parkula* Bengtson in Bengtson *et al.*, 1990

Type species: *Parkula bounites* Bengtson in Bengtson *et al.*, 1990.

Parkula bounites Bengtson in Bengtson *et al.*, 1990
(Fig. 5F)

Parkula bounites sp. nov.; Bengtson in Bengtson *et al.* 1990: 223, figs 149–151.

Parkula bounites Bengtson in Bengtson *et al.*; Demidenko in Gravestock *et al.* 2001: 101, pl. 9: 12–13.

Material. — One phosphatized operculum, ZPAL V.VI/103S3, from erratic boulder Me66.

Description. — Semicircular, phosphatized operculum with a crescentic cardinal shield. The external side is convex and covered with concentric growth lines and fine radial striae at the ventral margin. The internal side has a distinct marginal brim. Two cardinal processes are closely spaced. These observations confirm the features previously recorded in the Australian specimens (see Bengtson *et al.* 1990).

Remarks. — Wall was primarily calcitic and in acid residues the operculum may occur phospatized or as internal mould, but the latter is difficult to identify, unless bears distinctive features.

Occurrence. — Early Cambrian (Atdabanian/Botomian) Kulpara Formation and Parara Limestone, Horse Gully, Yorke Peninsula, Stansbury Basin, South Australia; King George Island, Antarctica.

Genus *Hyptiotheca* Bengtson in Bengtson *et al.*, 1990

Type species: *Hyptiotheca karraculum* Bengtson in Bengtson *et al.*, 1990.

Hyptiotheca karraculum Bengtson in Bengtson *et al.*, 1990
(Figs 9A–B, and 10A–E)

Hyptiotheca karraculum Bengtson; Bengtson *et al.* 1990: 228–229, figs 152–155.

Hyptiotheca karraculum Bengtson; Brock and Cooper 1993: 777, pl. 11: 13–15; pl. 13: 1–2.

Hyptiotheca karraculum Bengtson; Demidenko in Gravestock *et al.* 2001: 102, pl. 10: 3–6.

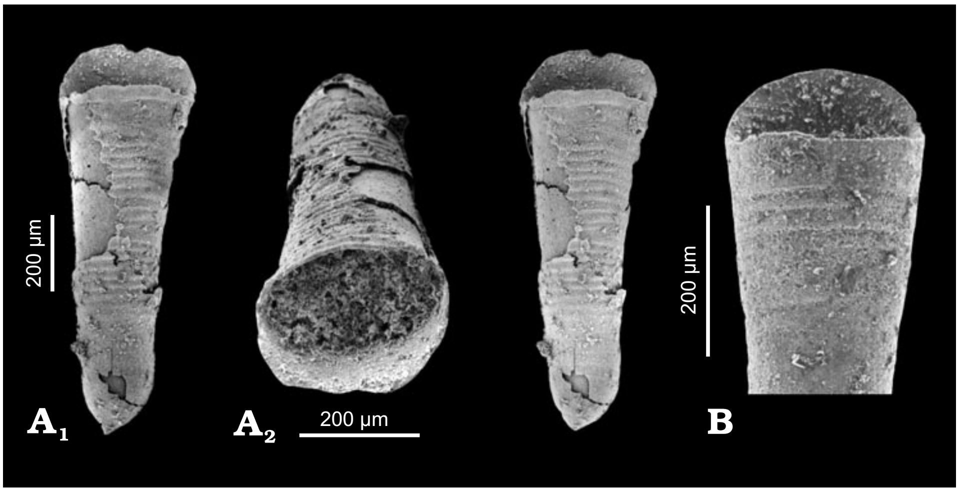

Fig. 9. **A$_1$**. *Hyptiotheca karraculum* Bengtson conch, view of dorsum, stereo-pair, note a slight median sinus in growth ribs, ZPAL V.VI/15U5, erratic Me33. **A$_2$**. Oblique apertural view of conch, dorsum at top. **B**. Apertural part of conch, view of dorsum, ZPAL V.VI/108S3, erratic Me66.

Material. — Ten well preserved specimens, ZPAL V.VI/15U5, 37S23, 106S3, 107S2, 108S3, 15, 110S9; from erratic boulders Me32, 33, 66.

Description. — Small conch up to 3 mm long, ovoid in cross-section, with dorsum more convex than venter (Fig. 10C$_2$, D$_3$). Conch conoidal with angle of divergence 15° in juvenile (Fig. 9A) up to 25° in the adult (Fig. 10A–E). Ligula short, about 0.5 or less of the apertural width and semi-elliptical in outline (Fig. 9A, B; Fig. 10C–D). The dorsal apertural margin is a little thicker, as in the Australian type specimens (Bengtson *et al.* 1990: fig. 154B), and meets with the ligula at an angle of 120°. Outer conch surface covered with densely spaced growth lines, developed as asymmetric, more steep toward the apex, transverse ribs. Ribs are parallel to apertural margin, with slight median sinus on dorsum (Figs. 8A$_1$, B and 9B$_3$, E) and parallel to ligula edge on venter. Inner surface of conch smooth. Initial part of conch bulbous (Fig. 10A–D), usually slightly convex apically, and with a wall that is thinner than the rest of the conch wall. Conch primarily calcitic, and in acid residues usually occurring as a more or less deeply phospatized shell wall (Fig. 9A) and as phosphatic internal moulds (Fig. 9A, Fig. 10E). Operculum not observed.

Remarks. — The Antarctic specimens demonstrate the distinctive features of shape and ribbed sculpture (Figs 9A, 10A–E), seen in the Australian ones (Bengtson *et al.* 1990).

Occurrence. — Early Cambrian (Atdabanian/Botomian) Kulpara Formation and Parara Limestone, Horse Gully, Yorke Peninsula, Stansbury Basin, South Australia; and King George Island, Antarctica.

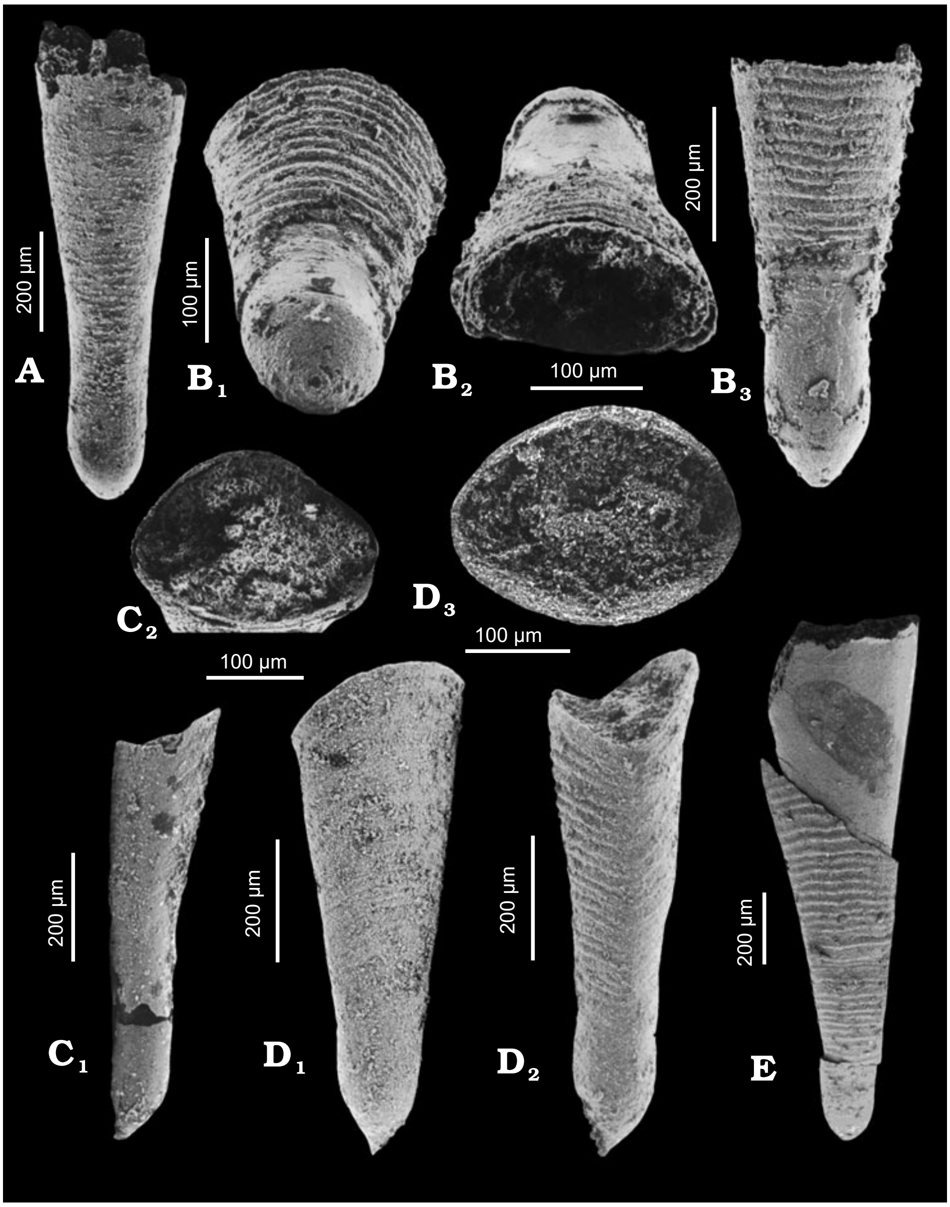

Fig. 10. **A**–**E**. *Hyptiotheca karraculum* Bengtson. **A**. Broken conch, view of venter, ZPAL V.VI/107S2, erratic Me66. **B$_1$**. Apical part of conch in oblique apical view, dorsum at top, ZPAL V.VI/106S3, erratic Me66. **B$_2$**. The same specimen in oblique apertural view, dorsum at top. **B$_3$**. The same specimen, view of dorsum, note ribs formed a slight median sinus. **C$_1$**. Complete conch in lateral view, dorsum to left, ZPAL V.VI/110S9, erratic Me66. **C$_2$**. The same specimen in apertural view, dorsum at top. **D$_1$**. Complete conch, oblique view of venter, ZPAL V.VI/108S15, erratic Me66. **D$_2$**. The same specimen in oblique dorso-lateral view. **D$_3$**. The same specimen in apertural view, dorsum at top. **E**. Internal mould with partially broken conch, view of dorsum; note a slight median sinus in the ribbed sculpture, ZPAL V.VI/37S23, erratic Me33.

"Hyolithes" conularioides Tate, 1892
(Fig. 11G_1–G_2)

"Hyolithes" conularioides sp. n.; Tate, 1892: 186, pl. 2: 1.

"Hyolithes" conularioides Tate; Bengtson in Bengtson *et al.* 1990: 231, fig. 156.

"Hyolithes" conularioides Tate; Demidenko in Gravestock *et al.* 2001: 103, pl. 10: 9.

Material. — Three internal moulds of poorly preserved specimens, ZPAL V.VI/112S8; from erratic boulder Me66.

Description. — Strongly tapering conch, with angle of divergence mainly about 30° and trapezoidal in cross-section. The venter is flat, the lateral sides are rounded, and the dorsum is convex with a pair of distinct longitudinal folds bounding a deep median sulcus (Fig. 11G_1–G_2). The inner surface of the conch is smooth. The juvenile part seems to be separated from the rest of the conch by a transverse, septum-like wall.

Remarks. — Incomplete internal moulds with partly adhered badly-preserved phosphatized conchs were recovered from one erratic boulder. Conchs with very distinctive dorsal furrow, size and shell shape are most similar to the specimens described from Early Cambrian, (Atdabanian–Botomian) Horse Gully, Curramulka and Mount Scott Range localities in South Australia (Bengtson *et al.* 1990, Gravestock *et al.* 2001).

Phylum, Class and Order uncertain
Family Cupithecidae Duan, 1984
Genus *Cupitheca* Duan in Xing *et al.*, 1984

Type species: *Paragloborilus mirus* He in Qian, 1977.

Remarks. — For concept of the genus, its full synonymy and species included see Bengtson in Bengtson *et al.* (1990: 203). Previous generic name *Actinotheca* Xiao *et* Zhou, 1984 has been preoccupied by tabulate coral genus *Actinotheca* French, 1889, and the next junior synonym is *Cupittheca* [*sic*] Duan (in Xing *et al.* 1984) which is apparently an inadvertent error (lapsus calami) of *Cupitheca* Duan (1984), which is hereby selected as the correct original spelling in the sense of the ICZN: Article 32.5.1 of the current fourth edition (International Commission on Zoological Nomenclature 1999). For detailed discussion and farther synonymy see Demidenko in Gravestock *et al.* (2001: 96–97).

Cupitheca holocyclata (Bengtson in Bengtson *et al.*, 1990)
(Fig. 11A–F, G_3)

Coleolella sp.; Wrona 1989: 543, pl. 7: 4.

Actinotheca holocyclata; Bengtson in Bengtson *et al.* 1990: 204, figs 134–136.

Actinotheca sp.; Wrona and Zhuravlev 1996: 17.

Cupittheca holocyclata (Bengtson in Bengtson *et al.* 1990); Demidenko in Gravestock *et al.* 2001: 97, pl. 9: 1.

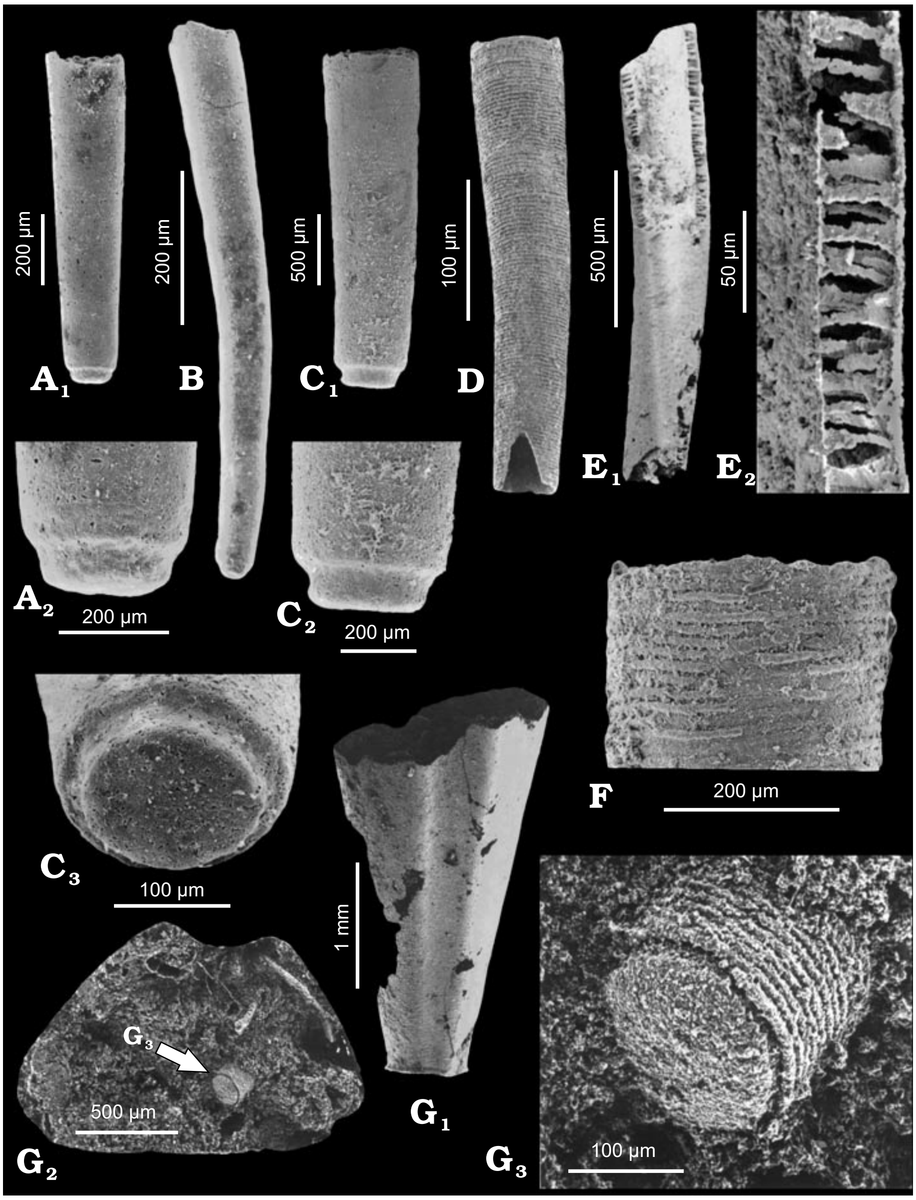

Fig. 11. **A**–**F**, **G_3**. *Cupitheca holocyclata* (Bengtson). **A_1**. Conch internal mould in lateral view, ZPAL V.VI/58S4, erratic Me33. **A_2**. The same, enlarged apical termination. **B**. Internal mould of conch in lateral view, ZPAL V.VI/105S15, erratic Me66. **C_1**. Conch internal mould in lateral view, ZPAL V.VI/15U7, erratic Me33. **C_2**. The same, enlarged apical termination. **C_3**. Detail of the same specimen in apical view. **D**. Conch in lateral view, ZPAL V.VI/39S22, erratic Me33. **E_1** Broken conch showing phosphatized wall structure in longitudinal section, ZPAL V.VI/36S14, erratic Me32. **E_2** Detail of the broken section, external surface at right. **F**. Detail of apertural part, ZPAL V.VI/29S10, erratic Me66. **G_1**. Internal mould of *"Hyolithes" conularioides* Tate conch, view of dorsum, ZPAL V.VI/112S8, erratic Me66. **G_2**. Apertural view of internal mould (dorsum at top) with apical conch of *Cupitheca holocyclata* (Bengtson) (arrowed). **G_3**. Enlargement of *Cupitheca holocyclata* (Bengtson) conch in oblique apical view.

Material. — Ten well preserved specimens, ZPAL V.VI/15U7, 29S10, 39S22, 36S14, 58S4, 105S15; from erratic boulders Me32, 33, 66.

Description. — Cylindrical to slightly tapering tube, straight or gently curved and circular to oval in cross-section. The outer surface is covered with densely and evenly spaced, symmetric transverse ribs, usually straight to weakly undulating sinuously. The inner surface is smooth. Conch closed apically by a septum-like transverse wall (Fig. 11A_2, C_2–C_3, G_3), usually slightly convex apically and thinner than the rest of the conch wall. Conch primarily calcitic, and in acid residues occurring as a more or less phospatized shell wall (Fig. 12E) or as a phosphatic internal mould (Fig. 11A–C, G_3). Broken conchs show phosphatized wall structure as a system of radial rods, apparently representing tubules (Fig. 11E_2). Operculum not observed.

Remarks. — Preservation is very similar to the Australian material (Bengtson *et al.* 1990: figs 134F–L, N, O, 136G), as well as to that of phosphatized tubes from the Lower Cambrian of the Montagne Noire, France (Kerber 1988: text-fig. 10). The Antarctic specimens demonstrate characteristic features, such as the distinctive termination (Fig. 11A_2, C_2–C_3) associated with the zone of decollation of the earlier formed shell, which is analogous to the repeated shedding of earlier ontogenic portions of the shell among Recent prosobranchs, e.g. Caecidae (Bandel 1996); for a detailed discussion of the biological implication see Bengtson *et al.* (1990).

Occurrence. — Early Cambrian (Atdabanian/Botomian) Kulpara Formation and Parara Limestone, Horse Gully, Yorke Peninsula, Stansbury Basin, South Australia; China; King George Island, Antarctica.

Class Helcionelloida Peel, 1991b

Remarks. — The explosive development of the Early Cambrian monoplacophoran molluscan fauna have currently attracted great interest of palaeontologists, because of the find of abundant and well-preserved fossil assemblages and because of their potential for biostratigraphic subdivisons of the Lower Cambrian (Missarzhevsky and Mambetov 1981, He *et al.* 1984, Hinz 1987, Kerber 1988, Qian and Bengtson 1989, Bengtson *et al.* 1990, Brock and Cooper 1993, Elicki 1994, Esakova and Zhegallo 1996, Runnegar and Jell 1976, Runnegar 1996, Gravestock *et al.* 2001). However, their taxonomy and relationships are still in a state of flux (*e.g.* Runnegar 1983, 1996; Runnegar and Pojeta 1985; Peel 1991a, b; Geyer 1994, Gravestock *et al.* 2001, Parkhaev 2002a). Most of them are placed in the Class Helcionelloida (Peel 1991a, b; Geyer 1994, Gubanov 1998, Gubanov and Peel 2000, 2001). It is, however, controversial to keep in this class the genera with whorled anisostrophic shells (*Pelagiella*, *Beshtashella* and relatives), which are also placed within gastropods (*e.g.* Landing *et al.* 2002; Parkhaev 2002a, b). No impressions of the soft-part anatomy are preserved on the helcionelloid internal moulds described from Antarctica, and in general, their fossils do not provide enough information to permit reliable evaluation and discussion of their suprageneric taxonomy. This is now clearly too much speculative. The univalved molluscan systematic accepted herein follows that of Peel (1991a, b) and Gubanov and Peel (2000, 2001).

Order Helcionellida Geyer, 1994
Family Helcionellidae Wenz, 1938
Genus *Pararaconus* Runnegar in Bengtson *et al.*, 1990

Type species: *Pararaconus staitorum* Runnegar in Bengtson *et al.*, 1990.

?*Pararaconus* cf. *P. staitorum* Runnegar in Bengtson *et al.*, 1990
(Fig. 12A–C)

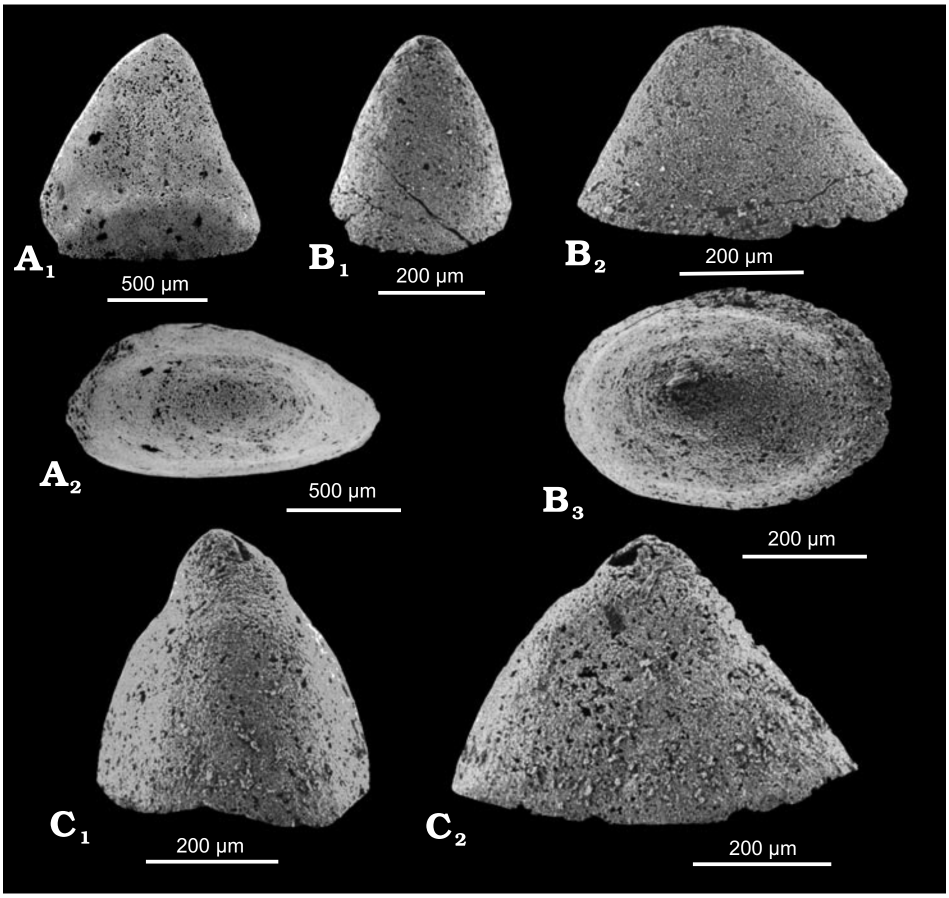

Fig. 12. **A**–**C**. Phosphatic internal moulds of ?*Pararaconus* cf. *P. staitorum* Runnegar. **A$_1$**. Phosphatic internal mould in right lateral view, visible is weakly preserved lateral ridge, ZPAL V.VI/52S3, erratic Me66. **A$_2$**. Apical view. **B$_2$**. Lateral view, ZPAL V.VI/112S4, erratic Me66. **B$_1$**. Anterior view. **B$_3$**. Apical view. **C$_1$**. Internal mould in posterior view, ZPAL V.VI/112S5, erratic Me66. **C$_2$**. The same specimen in lateral view.

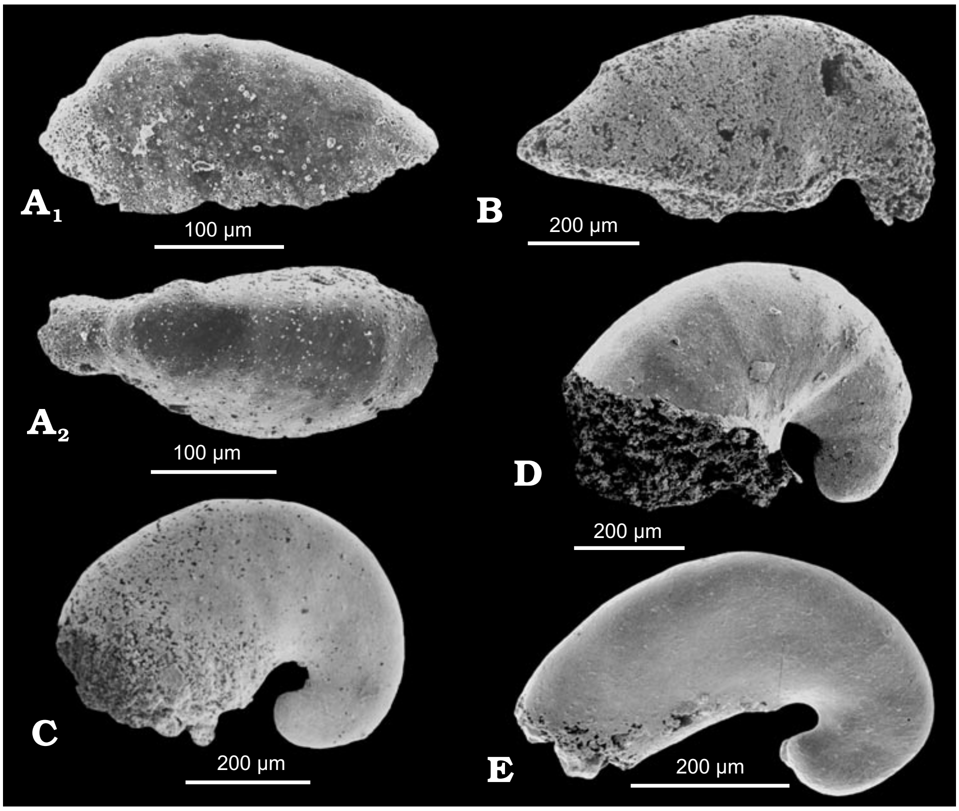

Fig. 13. **A$_1$**. Internal mould of ?*Yochelcionella* sp. in lateral view, ZPAL V.VI/32S1, erratic Me66. **A$_2$**. Apical view. **B**. Poorly preserved internal mould of *Anabarella* cf. *argus* Runnegar, in right lateral view, ZPAL V.VI/109S2, erratic Me66. **C**–**E**. Internal moulds of *Pelagiella madianensis* (Zhou and Xiao), in right lateral view. **C**. ZPAL V.VI/32S35, erratic Me33. **D**. ZPAL V.VI/36S5, erratic Me33. **E**. ZPAL V.VI/21S15, erratic Me33.

Material. — Three phosphatic internal moulds, ZPAL V.VI/52S3, 112S4, 5, from erratic boulders Me33, 66.

Description. — Shell cap-shaped, highly conical, slightly laterally compressed. The apex is gently rounded, and slightly displaced posteriorly. The aperture has an elliptical outline and a slightly flaring margin. The surface of the internal mould is smooth. No texture pattern or muscle scars have been observed on the surface moulds.

Remarks. — The shell was apparently originally calcitic or aragonitic.The shape of the moulds represents shells very similar to the phosphatized conchs identified as *P. staitorum* Runnegar from the Parara Limestone (Runnegar in Bengtson *et al.* 1990). Internal moulds differ from the originally described Australian material in lacking paired lateral ridges owing to incompleteness of their moulding. Internal moulds probably represent more of the apical part of the shell, since apertural margin and lateral ridges are rarely preserved.

Traces of weakly preserved lateral ridges are visible on one specimen (Fig. $12A_1$).

Occurrence. — Early Cambrian, Atdabanian–Botmian stages of the Parara Limestone, Horse Gully, South Australia; King George Island, Antarctica.

Family Yochelcionellidae Runnegar and Jell, 1976
Genus *Yochelcionella* Runnegar and Pojeta, 1974

Type species: *Yochelcionella cyrano* Runnegar and Pojeta, 1974.

?*Yochelcionella* sp.
(Fig. 13A)

Material. — One phosphatic internal mould, ZPAL V.VI/32S1, from erratic boulder Me33.

Description. — Microscopic cyrtoconic shell, laterally compressed, with trace of a broken-off tube or snorkel on concave side.

Remarks. — A single badly preserved, incomplete phosphatic internal mould was recovered from one erratic boulder. The shape and size of the internal mould fragment are most similar to the examples of *Y. chinensis* Pei, 1985, however, the latter has a much more strongly differentiated apex.

Family Stenothecidae Runnegar and Jell, 1980
Genus *Anabarella* Vostokova, 1962

Type species: *Anabarella plana* Vostokova, 1962.

Anabarella cf. *argus* Runnegar in Bengtson *et al.*, 1990
(Fig. 13B)

Material. — One phosphatic internal mould, ZPAL V.VI/109S2, from erratic boulder Me66.

Description. — Laterally compressed cap-shaped shell with distinct notch between apertural margin and umbonal part of the conch. No microsculpture has been observed on the internal mould surface.

Remarks. — This single badly preserved specimen recovered from one erratic boulder shows the noch, which is similar in *P. argus* described by Runnegar in Bengtson *et al.* (1990: fig. 164L).

Order Pelagiellida Runnegar and Pojeta, 1985
Family Pelagiellidae Knight, 1952
Genus *Pelagiella* Matthew, 1895

Type species: *Cyrtolites atlantoides* Matthew, 1894.

Pelagiella madianensis (Zhou and Xiao, 1984)
(Fig. 13C–E)

Pelagiella sp.; Gaździcki and Wrona 1986: 611, fig. 7d.

Pelagiella sp.; Wrona 1989: 540, pl. 10: 4.

Pelagiella adunca (He et Pei in He *et al.*, 1984); Runnegar in Bengtson *et al.* 1990: 254: figs 168E–K.

Pelagiella cf. *P. adunca* (He et Pei in He *et al.*, 1984); Brock and Cooper 1993: 780: figs 13: 11–18.

Pelagiella madianensis (Zhou and Xiao); Parkhaev in Gravestock *et al.* 2001: 195, pl. 46: 1–12, pl. 47: 1–8. [full synonymy]

Material. — Numerous phosphatic internal moulds, ZPAL V.VI/21S15, 32S35, 36S5, from erratic boulder Me33.

Description. — Microscopic to tiny shell, dextrally coiled with an incipient and rapidly expanding open whorl, and with a narrow, laterally flaring, asymmetric aperture. Apical region of coil is very variable, bulbous or hook-shaped. Shell apparently originally aragonitic. The surface of the internal mould is smooth, except for rare traces of fine growth lines (Fig. 13C–D). No texture patterns nor muscle scars.

Remarks. — The shape of the internal moulds is similar to examples from the Parara and Ajax Limestones (Runnegar in Bengtson *et al.* 1990), and Wirrealpa Limestone of southern Australia (Brock and Cooper 1993).

Occurrence. — Early to Middle Cambrian, Xinji Formation, Henan Province, Sichuan Province, Yutaishan Formation, Anhui Province (China); Ajax and Wirrealpa Limestones and Mernmerna Formation, Flinders Ranges and Parara, Ramsay, Stansbury and Coobowie limestones, Yorke Peninsula (South Australia); King George Island, Antarctica.

Order Macluritida Cox and Knight, 1960
Family Onychochilidae Koken, 1925
Genus *Beshtashella* Missarzhevsky in Missarzhevsky and Mambetov, 1981

Type species: *Beshtashella tortilis* Missarzhevsky in Missarzhevsky and Mambetov, 1981.

Remarks. — The genus is grouped in the Onychochilidae together with *Yuwenia* Runnegar, 1981 (junior synonym *Kistasella* Missarzhevsky, 1989) as was suggested by Parkhaev (in Gravestock *et al.* 2001) on the basis of their similar shell shape; for detailed discussion see Missarzhevsky (1989), Runnegar (in Bengtson *et al.* 1990) and Parkhaev (in Gravestock *et al.* 2001), Parkhaev 2002a.

Beshtashella tortilis Missarzhevsky, 1981
(Fig. 14A–E)

Beshtashella tortilis Missarzhevsky; Parkhaev in Gravestock *et al.* 2001: 198, pl. 43: 10–16. [full synonymy]

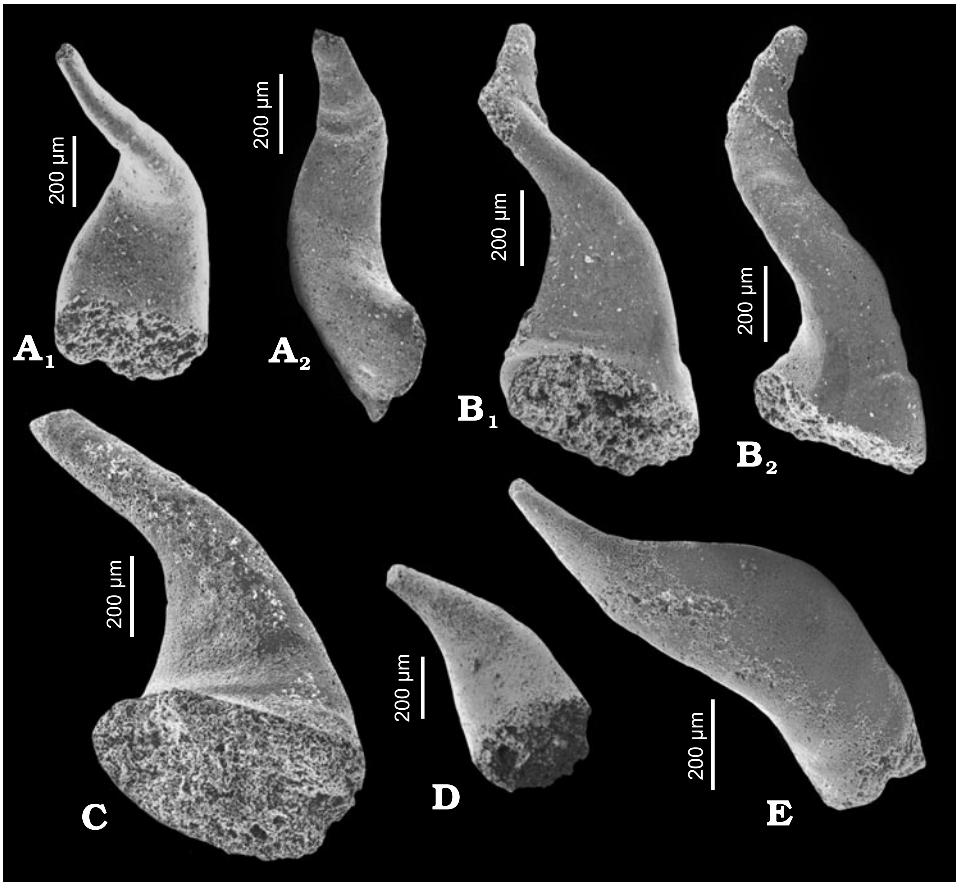

Fig. 14. **A**–**E**. *Beshtashella tortilis* Missarzhevsky, **A$_1$**. Broken internal mould in oblique view, ZPAL V.VI/103S9, erratic Me66. **A$_2$**. Lateral view. **B$_1$**. Internal mould in oblique view, ZPAL V.VI/36S9, erratic Me33. **B$_2$**. Lateral view. **C**. Internal mould in oblique apertural view, ZPAL V.VI/35S5, erratic Me33. **D**. Apical fragment of phosphate internal mould, in oblique apertural view, ZPAL V.VI/32S24, erratic Me33. **E**. Internal mould in lateral view, ZPAL V.VI/35S13, erratic Me32.

Material. — Fourteen phosphatic internal moulds, ZPAL V.VI/32S24, 35S5, 13, 36S9, 103S9, from erratic boulders Me32, 33 and 66.

Description. — Minute (up to 1.5 mm), sinistrally coiled univalve shells, with a high helical spire and an oval, asymmetrically flared aperture. Apical region (protoconch) clearly separated from adult part (Fig. 14B). The surface of the internal mould is smooth, with occasionally visible traces of comarginal, fine growth lines (Fig. 14A–C, E). No texture patterns nor muscle scars.

Remarks. — The shells was probably calcitic or aragonitic. The variable shape of the shell possibly is the result of its un-coiled or loose-coiled whorls. This, as well as the co-ocurrence of the most tightly coiled forms, even in the same samples, led Parkhaev (in Gravestock *et al.* 2001) to suggest that *Yuwenia bentleyi* Runnegar, 1981, *Y. juliana* Elicki, 1994 and *Kistasella spiralis* Missarzhevsky, 1989 are junior synonyms of *B. tortilis*. The polygonal microstructure recently discovered on internal phosphatic shell moulds of *B. tortilis* has been interpreted as a replica of single columnar muscle (Parkhaev 2002b). The latter, however, could be a pair of muscles coalesced during shell evolutionary transformation from cap-shaped, cyrtoconic to helically coiled morphologies, and therefore does not allow for unequivocal higher-level systematic assignation (Parkhaev 2002b).

Occurrence. — Early Cambrian, upper Atdabanian, Beshtash Member, Beshtash section, Talassky Alatau, Kirgizstan; Maly Karatau, Kazakhstan; Kharaulakh, Yakutia, Siberian Platform; Early Cambrian, Xiaoping Member, Tongying (Dengying) Formation, Tanabao, Xihaoping, Fangxian, Hubei (China); Early Cambrian, Parara Limestone, Horse Gully (Stansbury Basin), Yorke Peninsula (South Australia); Marianian strata (?uppermost Atdabanian–Botomian), Görlitz Syncline (eastern Germany); King George Island, Antarctica.

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