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Cambrian stratigraphy and faunas at Mount Arrowsmith, northwestern New South Wales

GLENN A. BROCK & IAN G. PERCIVAL


Mount Arrowsmith is situated 200 km north of Broken Hill in far western N.S.W., near the north-western extremity of the Koonenberry Belt. Formal definitions are provided for formations correlated with part of the Gnalta Group on the south-western flank of Mount Arrowsmith. The Pincailly Formation, of latest Early Cambrian (Ordian to Early Templetonian) age, includes shales and thin-beded limestones with a total thickness of 130 m. Fauna present includes the lingulate brachiopods Eooobulus sp., Eothele granulata Roberts, Protorete millsi n. sp., Micromitra nerrambuga Kruse, molluscs Pelagiella medianensis (Zhou & Xiao) and hyolith taxa associated with small shelly fossils, including chancelloriids, hyolithelmintes, spines of the bivalved arthropod Mongoliolutus and problematic forms. The phosphatic assemblage closely resembles broadly synchronous sequence 1 faunas from the First Discovery Limestone Member of the Coonignian Formation further south along the Koonenberry Belt, carbonate sequences in the Daly, Wiso and Georgina basins of northern Australia, and the Arrowie and Stansbury basins in South Australia. Conformably overlies the Pincailly Formation is the Wydjiah Formation, dominated by quartzose sandstones in its lower and upper parts. The Pimpipra Member, an interval of thick oncotic dolostones with interbedded shales in the middle of this formation, yields a sparse fauna dominated by hyoliths and algae, with rare lingulate brachiopods (Protorete millsi n. sp.; Eooobulus sp. and Micromitra nerrambuga Kruse). No fossils have been recorded in the conformably overlying Wyarra Shale at the top of the Cambrian section. The stratigraphic break between the Cambrian Gnalta Group equivalents and the Early Ordovician Mutawintji Group (represented at Mount Arrowsmith by the Yandaminta Quartzite and overlain by Tabita Formation) corresponds to the Delamerian Orogeny.

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MOUNT ARROWSMITH is situated towards the north-western extremity of the Late Proterozoic - Palaeozoic Koonenberry Belt (previously called the Wonominta Block, sensu Mills 1992) in the north-west corner of New South Wales (Fig. 1). In this region of generally poor outcrop and low relief, Koonenberry Belt sediments are, with few exceptions, mostly inconspicuous or largely buried beneath younger regolith. The comparatively well-exposed successions at Mount Arrowsmith provide an opportunity to collect in detail through measured sections, enabling relatively precise biostratigraphic correlations to be made with outcrops elsewhere in the Koonenberry Belt, and further afield to the Flinders Ranges, 300 km to the southwest in South Australia. Accurate dating of the earliest Palaeozoic (latest Early Cambrian) strata at Mount Arrowsmith is of significance in constraining the timing of the Delamerian Orogeny in this region.

PREVIOUS INVESTIGATIONS
Mount Arrowsmith is largely composed of Proterozoic alkaline volcanic rocks, including basaltic pillow lavas and tuffs, intercalated between an eastern and western belt of metasediments (Mills 1992). The volcanic suite, termed the Mount Arrowsmith Volcanics by Crook (1980), was analysed by Crawford et al. (1997) who determined a SHRIMP zircon age of 586 ± 7 Ma for alkaline rocks 150 km to the south-east near Mount Wright (though distinct from the
younger Mount Wright Volcanics), which they confidently correlated petrographically and geochemically with those at Mount Arrowsmith. The adjacent belts of metasediments, named the Kara Beds by Mills (1992), are also believed to be of late Neoproterozoic age; although some shelly fragments identified in a limestone from the western belt (Percival & Pickett 1996) suggest the possibility of an extension into the earliest Cambrian.

Wotruba (1967) originally reported the discovery of Middle Cambrian and Early Ordovician sediments on the western side of Mount Arrowsmith. Wotruba’s mapping remained, until very recently, the most detailed published documentation of the outcrop of these Palaeozoic units. In the Cambrian section, the formations established by Warris (1967) have not previously been formally defined. For the Early Ordovician succession, Webby (1981) substituted stratigraphic names adopted from unpublished research by Warris (1967) to replace the informal nomenclature of Wotruba (1967) (Fig. 2).

Wotruba’s member A is now referred to as the Pinchally Formation, and members B and C are designated the Wyjdah Formation and its Pimpira Member, respectively. Wotruba’s member D now approximates the Wyara Shale. The Cambrian section is most likely faulted against (rather than unconformably overlain by) the Early Ordovician Yandaminta Quartzite (member E of Wotruba), which is conformably overlain by the Tabita Formation (member F) and in turn the Pingilly Formation (Wotruba’s member G). These Mutawintji Group strata unconformably overlie the western belt of the Kara Beds.

Biostratigraphic study of the region was initiated by Warris (1967); much of this work remains unpublished, but a brief outline of fossil distribution was provided later (Warris 1969). Relatively little emphasis was placed on palaeontology of the Cambrian section. In contrast, Warris (1969) provided an insight into the abundance and diversity of the Early Ordovician faunas, comprising mainly nautiloids, bivalves, gastropods, brachiopods, trilobites, ostracodes and conodonts. The latter were documented in detail by Zhen et al. (2001, 2003) and Zhen & Percival (2006) who determined an age in the lower Oepikodous evae Zone for the Yandaminta Quartzite and Tabita Formation. Other fossils described thus far from these formations include the nautiloid Anthoceras arrowsmithense (Crick & Teichert 1983; revised Stait & Laurie 1985), the enigmatic mollusc Janospira (Paterson 2001), two new taxa of articulate brachiopods (Paterson & Brock 2003), and Prosopiscus, a widely distributed trilobite (Paterson 2004).

**STRATIGRAPHY**

**Pinchally Formation**

The name Pinchally Formation was first published, without definition, in the legend of the Carnamah 1:500 000 geological map in 1995. The concept of the unit and its mapped distribution is founded on unpublished studies by Warris (1967), who named the formation ‘Pinchally’ homestead, situated 5 km southwest of the outcrop. The Pinchally Formation also corresponds exactly to member A of the informal nomenclature established by Wotruba (1967), who reported a total measured thickness of 183 m, whilst noting that an additional 95 m (approximately) of Cambrian shales were exposed sporadically down-section. Differences between Wotruba’s cumulative estimate of 278 m and our own measurement of 260 m are most likely attributable to variability of coverage of these cryptic outcrops by outwash fans of intermittent creeks draining the western slopes of Mount Arrowsmith. Thus the bottom of the formation is ill-defined (in our mapping it was placed at a discontinuous horizon of carbonate concretions, that failed to yield identifiable organic remains when dissolved in acetic acid), whereas the top is easily recognised as the base of the overlying succession of reddish-brown flaggy sandstones of the Wyjdah Formation.

The type section of the Pinchally Formation is located between GR 55707E/5661400mN and 557360mE/6661550mN on the southwest flank of Mount Arrowsmith, approximately 2 km north of McDonald’s Tank on the main track between ‘Pinchally’ and ‘Mount Arrowsmith’ homesteads (Figs 1, 2). This section was chosen as it represents the maximum thickness of the formation. Since the vast majority of the unit is composed of rapidly weathering grey-green phyllitic siltstone and shale, frequently exhibiting a cleavage-imparted fissility, outcrops are generally poor. Three thin-bedded limestones and cross-bedded sandstones with a carbonate matrix occur over an interval of 90 m towards the top of the shale-dominated succession (Fig. 2). The thickest of these beds is 2.7 m, but they

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*Fig. 1. Geographical map of the Lower Palaeozoic succession exposed on the south-west flank of Mount Arrowsmith, far-western New South Wales. The location of the measured type section through equivalents of the Cambrian Gnulta Group is shown in the lower third of the figure, opposite the regional locality map. Detailed mapping by Percival & Brock, based on reconnaissance mapping by B. Stevens & K.J. Mills (Geological Survey of NSW).*
are variable along strike and occasionally lens out. Thin sections of the limestones reveal them to be peloidal wackestones with abundant shelly grains, including whole hyoliths; some large oncoids are present surrounding a hyolith nucleus. The limestones (e.g. samples C1515, 21/9.1A, B, 21/9.7A, B, C1417, C1516) yield a diverse microfauna including chancelloriid spicules, lingulate brachiopods, molluscs, hyolithids, hyolithelinthes and echinoderm sclerites. Wopfner (1967) reported an identification of *Xystridura* amongst trilobite fragments from the lower of these carbonates.

**Wydjahl Formation**

The Wydjahl Formation conformably overlies the Pinacally Formation. The boundary between these units is marked by the appearance of a distinctive red-brown silicified sandstone with a thin-bedded flaggy outcrop. The Wydjahl Formation is readily divisible into three parts, with interbedded dolostones, phyllitic siltstones and shales of the Pimpira Member separating a lower and upper upwards-coarsening sequence of sandstones culminating in conglomeratic horizons. The name of the formation, derived by Warris (1967) from Wydjahl Well situated 17.5 km due north of the type section, was - like the Pinacally Formation - first published without definition in the legend to the Curramona 1:500 000 geological map (1995). The Pimpira Member was named by Warris (1967) after Pimpira Tank (GR 553500mE 6674250mN) but similarly has not been formally described. The only published reference to this unit was provided by Scheibner & Basden (1998, p. 99) in a caption to a field photograph of the distinctive dolostone beds. Wopfner (1967) recognised the main characteristics of the formation and its dolomitic member as his member B (= lower Wydjahl Formation) and member C (= Pimpira Member), but does not appear to have separately distinguished the upper Wydjahl Formation, whereas the threefold subdivision of the formation was clearly recognised by Warris (1967). Thickness of the Wydjahl Formation was measured in the type section (continued from the underlying Pinacally Formation) at 250 m, including 87 m for the lower unit, 74 m for the Pimpira Member, and 89 m for the upper Wydjahl. Warris (1967) gave an estimated thickness for the whole formation of about 270 m, including approximately 111 m for the lower unit overlain by 64 m of Pimpira Member. For members B and C of the Cambrian succession, Wopfner (1967) measured thicknesses of 123 m and 124 m, respectively.

Cross-bedded sandstone at the base of the Wydjahl Formation is fine-grained and moderately well-sorted, with subangular mineral grains (predominantly quartz), rare volcanic clasts, and eroded fossil fragments including chancelloriid spicules, all cemented by calcite.

Overlying this flaggy sandstone is nearly 40 m of phyllitic cleaved siltstone which is exposed over less than half this interval, with rare thin dolomitic beds confined to the lowermost 12 m. This section is similar in appearance to the underlying Pinacally Formation. At 39 m above the base of the Wydjahl Formation, however, the lithology abruptly changes to a very fine grained, extremely well-sorted quartz sandstone of blocky habit, which coarsens upwards through the succeeding 45 m to red-brown sandstone of increasingly gritty texture, culminating in a conglomerate with conspicuous well-rounded quartz pebbles. The conglomerate is poorly to moderately well-sorted, with grainsize varying from fine to coarse, segregated into poorly defined layers. Larger clasts are well-rounded compared to the smaller mineral grains (mainly quartz) which are subrounded. Wopfner (1967) interpreted some lithologies from this section as exhibiting tuffaceous affinities. Although eroded clasts derived from older volcanic terrains are present, we found no definitive evidence for contemporaneous volcanism. Occurrence of a variety of rock types, including foliated schist and altered volcanic clasts, in sandstones and conglomerates of the Wydjahl Formation suggests that these represent the end result of several erosional cycles culminating in shallow marine deposition.

Four to five thick and laterally continuous dolostone beds, separated by rhythmic phyllitic horizons, characterise the Pimpira Member. This unit is defined to extend between the first and last occurrences of prominent dolostone beds, alternating with phyllites. In some places, such as the type section, up to 17 dolostone beds, representing a total thickness of 8-9 m (slightly greater than one-eighth the total measured thickness of 64 m for the Pimpira Member), are present, though the majority of these are very thin and intermittent. The thicker dolostones are generally massive-bedded, whereas thinner beds clearly show finer parallel laminations. One particular bed (illustrated by Wopfner, 1967, plate II-2) is a distinctive slump horizon. In thin section the dolostones have the appearance of a chaotic breccia, induced by juxtaposition of stylolite-bounded clumps of wackestone, mudstone

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**Fig. 2.** Occurrence of taxa described from samples within the measured type section through the Pinacally and Wydjahl formations at Mount Arrowsmith.
and occasional packstone. Large oncolites are particularly prominent in dolostones in the upper part of the member (e.g. sample 21/9.20). Three levels in the Pimpira Member yield a shelly fauna, less diverse than is found in the Pincola Formation (Fig. 2) with no new occurrences. The fauna also suggests a late Early Cambrian age, similar if not identical to the underlying Pincola Formation, and implying little time gap between deposition of these two units.

The upper Wydjah Formation above the Pimpira Member is nearly identical in thickness and lithology to the lower upward-coarsening sequence. The conglomerate marking the end of the second upwards-coarsening sequence, whilst present in the measured type section, is intermittent in exposure, or else was not developed everywhere at the boundary.

Wyarra Shale
The unfossiliferous Wyarra Shale conformably overlies the Wydjah Formation and is itself faulted against the Yandaminta Quartzite of Early Ordovician age. The name of the unit, first informally recognised by Warris (1967), is derived from Wyarra Tank, situated 25 km south-southeast of Mount Arrowsmith. The Wyarra Shale is readily recognised by absence of sand-sized (and coarser) lithologies compared to the underlying unit. Outcrop of the Wyarra Shale, which consists predominantly of strongly cleaved maroon and purple shales with some khaki-coloured beds, is confined to a north-plunging syncline bounded along much of its eastern and western margins by the upper Wydjah Formation. Thickness of the unit is very difficult to estimate with any precision due to the fissile nature of the lithology, lack of marker beds, and structural complications, but it probably is of the order of 50 m. Warris (1967, p. 81) reported a comparable estimate of “at least 150 feet”. Member D of Wopfner (1967) is, however, considerably thicker (approximately 500 feet, or about 160 m) than our estimate, and may include beds assigned by us to the upper Wydjah Formation.

REGIONAL CORRELATION AND BIOSTRATIGRAPHY
The position of the Early-Middle Cambrian boundary in Australia and elsewhere has long been the subject of intense debate. Traditionally, the Australian Ordian/Early Templetonian Stage (= *Xystridura templetonensis*/Redlichia chinensis Zone) sensu Ōpik (1968) was considered to be early Middle Cambrian in age, but mounting evidence suggests that a large part of this stage should be regarded as latest Early Cambrian, based on correlation with the Lungwangmisoan Stage of China and the Toyonian Stage of Siberia (Shergold 1995; Kruse 1998; Geyer & Shergold 2000; Kruse et al. 2004; Geyer 2005). The recent consensus vote by members of the International Subcommission on Cambrian Stratigraphy (ISC) that the Cambrian Period should be subdivided into four (rather than three) series and ten stages (Babcock et al. 2005) has focussed more attention on definition of series and stage boundaries in the Cambrian. In a review of five possible levels to define the base of the Middle Cambrian (= base of Series 3, Stage 5 of Babcock et al. 2005, fig. 1), Geyer (2005, fig. 8) lists a number of trilobite-based alternatives, the most favoured of which (FAD of *Oryctocephalus indicus* or FAD *Ovatoryctocara granulata*/*Kiskinella cristata*) would place Ordian-Early Templetonian strata in Australia in the latest Early Cambrian or in the undefined Cambrian Series 2, Stage 4 of Babcock et al. (2005). Kruse et al. (2004, pp. 18-19), Paterson & Brock (in press) and Jago et al. (2005) have recently reviewed the history of this boundary in Australia. Jeff (1983) proposed the FAD of *Pagetia* as a potential marker for establishing the Early-Middle Cambrian boundary (and therefore the base of the Ordian Stage) in Australia based on the widespread occurrence of this taxon in central and northern Australia (Gravestock & Shergold 2001). The documentation of *Pagetia* from the Coobowie Limestone in the Stansbury Basin of South Australia (Ushatinskaya et al. 1995; Gravestock et al. 2001) provides direct correlation with Middle Cambrian sequences in northern Australia and has been used to define the epoch boundary in South Australia (Gravestock & Shergold 2001).

Krusze et al. (2004, p. 19) expressed concern that the *Pagetia* datum equates to a “stratigraphically higher Early-Middle Cambrian boundary level employed in Russia”. However, given that most Cambrian workers (Gravestock 1984, 1995; Shergold 1996; Young & Laurie 1996; Brock et al. 2000; Jago et al. 2002; Zang et al. 2004; Paterson & Brock in press) have successfully correlated the South Australian Lower Cambrian succession using the Siberian stage subdivision, it seems reasonable to follow Gravestock & Shergold (2001) and use this datum as an approximation of the Early-Middle Cambrian boundary in Australia. Thus, we consider many of the classic “Ordian” successions in western Queensland, the Northern Territory, South Australia and the Gnalta Shelf to be late Early Cambrian in age.

Correlation with Gnalta Group
The Gnalta Group in the southern part of the Koonenberry Belt (vicinity of Mount Wright and Mutawintji National Park) comprises the
Mount Wright Volcanics at the base, overlain conformably by the Cymbic Vale Formation. An unconformity separates the latter from the Coonigan Formation, which is in turn overlain by an unnamed unit of silicic ash-flow and volcanic conglomerate about 200 m thick at the top of the Gnalta Group (Leitch et al. 1987; Mills 1992).

The Gnalta Group is unconformably overlain by the Noutumbula Sandstone, basal formation of the Late Cambrian to Early Ordovician Mutawintji Group. This unconformity represents the disruption to sedimentation and structural dislocation caused by the Delamerian Orogeny.

From isolated limestone lenses in the upper part of the Mount Wright Volcanics, Kruse (1982) described 13 archaeocyathid species, calling this assemblage Archaeocyathid Fauna 1. Kruse & Shi (in Brock et al. 2000) assigned an early Botoman equivalent age to Fauna 1, which also extends into the lower half of the Cymbic Vale Formation, with occurrences in two allochthonous limestone lenses. In the upper part of the Cymbic Vale Formation this fauna is completely replaced by Archaeocyathid Fauna 2, having no species in common with the earlier assemblage (Kruse 1978, 1982). This younger fauna is equivalent to the Syringocnema favus archaeocyathan fauna of mid to late Botoman age in South Australia, with trilobites described by Jago et al. (1997) and Paterson (2005) confirming this age determination. Paterson (2005), in a revision of two pivotal trilobite taxa, recognised the presence of Pagetia (Discomesites) fragum and Eostaingia cerastes from the upper Cymbic Vale Formation and noted a direct correlation with the Paraara janesae Zone of South Australia and the presence of conspecific taxa in the Shackleton Limestone in the Transantarctic Mountains, Antarctica.

On the western limb of the Gnalta Syncline, the Cymbic Vale Formation is unconformably overlain by the Coonigan Formation (Roberts & Jell 1990, fig. 2). The Coonigan Formation includes the First Discovery Limestone Member, which has yielded a very diverse fauna comprising molluscs (Runnegar & Jell 1976), corals (Jell & Jell 1976), sponges (Pickett & Jell 1983) and brachiopods (Roberts & Jell 1990). Presence of the brachiopods Eothele granulata, Micromitra nannomobifera and possibly Eooebalus sp. (= ?L. bynguamoensis) in the Pinchally Formation and (at least for the latter two taxa) the Pimpina Member of the Wydjah Formation provides a modicum of correlation with the First Discovery Limestone Member. However, it should be noted that the brachiopod fauna described by Roberts & Jell (1990) with a total of 20 taxa (mainly silicified) is significantly more diverse than the unsilicified Mount Arrowsmith fauna of 4 taxa. The precise stratigraphic ranges of these brachiopod taxa is also poorly constrained and it is thus possible that they may have a long stratigraphic range not appropriate for detailed biostratigraphic correlation. Roberts & Jell (1990, p.260) note that the brachiopod fauna (at least at generic level) from the First Discovery Limestone Member can be correlated with the brachiopod fauna described by Rowell (1980) from Early-Middle Cambrian boundary beds of the Pioche Shale in central Nevada. Jell (1975) described silicified specimens of the eodiscid trilobites Pagetia silicunda and Pagetia sp. cf. quebecensis from the same horizons that yielded the silicified calcareous and phosphatic brachiopods described by Roberts & Jell (1990). Other trilobite taxa reported (but not formally described) from the First Discovery Limestone Member include species of Redlichia, Xystridura, Peronopsis, Dinesus, Kootenia and Onaraspis (Roberts & Jell 1990). Pagetia silicunda and Pagetia sp. cf. quebecensis are also recorded from the white micaceous shale band at the top of the Coonigan Formation (some 60 m above the brachiopod-bearing horizons) along with a diverse trilobite fauna including Xystridura, Dinesus, Oryctococephalus and Pentagnostus, typical of the Peronaspis longinqua or Triplognathus gibbus zones of the early Middle Cambrian (Templetonian) age. The presence of Redlichia and Onaraspis in the First Discovery Limestone Member suggests correlation with the Redlichia chinesis biozone in China, regarded by us as latest Early Cambrian in age. Significantly, apart from a few indeterminate trilobite fragments tentatively referred to Xystridura by Wopfner (1967), trilobites are not apparent in the Mount Arrowsmith succession, thus making age assessment and direct correlation difficult.

Perhaps more pertinent is the presence of Pelagiella madianensis in the upper part of the Pinckally Formation and the lowermost horizon of the Pimpina Member in the Wydjah Formation (Fig. 2). This species is the eponymous taxon of the Pelagiella madianensis mollusc zone recognised by Gravestock et al. (2001) in the Stansbury Basin, South Australia with a stratigraphic range from the late Early Cambrian (Toyonian) through to the earliest Middle Cambrian (based on the co-occurrence of P. madianensis Zone with Pagetia sp. in the Coobowie Limestone in the Stansbury Basin – see Gravestock et al. 2001). The absence of Pagetia in the Mount Arrowsmith succession means that the Middle Cambrian has yet to be identified in the area, though based on stratigraphic grounds the Early-Middle Cambrian boundary should be sought in the upper Wydjah Formation or Wyarra Shale.

The presence of distinctive small shelly fossils
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**Fig. 3.** Correlation of the Cambrian section at Mount Arrowsmith with successions in the central Kooneenberry Belt of NSW, and sequences in South Australia, Northern Territory, and Antarctica discussed in the text.

such as *Hyolithella micans*, *Torellia laevigatus*, *Mongolitubulus squamifer*, *Conototha cf. C. australiensis*, *Hyptothena baccracum* along with *Pelagieilla madanian* in the Pinacally Formation (Fig. 2) invites comparison with latest Early Cambrian (Toyonian) faunas derived from the Wirrealpa and Ramsay Limestone, South Australia (Brock & Cooper 1993) and glacial erraticas on King George Island (Wrona 2004). Unfortunately, small shelly fossil taxa from the First Discovery Limestone Member have not been formally described, frustrating further correlation with the Mount Arrowsmith succession. The lack of faunal diversity and relatively poor preservation of the Mount Arrowsmith faunas hinders precise age determination, but on current evidence, and taking into account recent revisions of the Australian Cambrian biostratigraphic scheme, a latest Early Cambrian (Toyonian to Ordian-early Templetonian) age would seem the most appropriate at this time (Fig. 3).

**SYSTEMATIC PALAEONTOLOGY**

*Repository.* All specimens designated by MMNC numbers have been lodged in the micropalaeontological collection of the Geological Survey of N.S.W., housed at the Londonderry Geoscience Centre in western Sydney.

Phylum UNCERTAIN
Class COELOSCLERITOPHORA Bengtson & Missarzhevsky, 1981
Order CHANCELLORIIIDA Walcott, 1920
Family CHANCELLORIIIDAE Walcott, 1920

**Discussion.** The higher systematic position of the chancellorids has long been the subject of keen debate; some workers preferring a sponge affinity (Walcott 1920; Sdzyu 1969; Butterfield & Nicholas 1996), others indicating the group has morphological features inconsistent with a poriferan affinity (Goryansky 1973; Bengtson & Missarzhevsky 1981; Bengtson et al. 1990; Mehl 1998; Janussen et al. 2002; Randell et al. 2005). Bengtson & Missarzhevsky (1981) erected the new class "Coeloscleritophora" to encompass those organisms with a scleritome constructed of hollow, calcareous star- or scale-shaped sclerites. The two major groups traditionally included in the class are the sachidiids (halkierids, wiwaxiids, siphogonuchitids and ninellids) and the chancellorids. However, the documentation of articulated halkierids from the Lower Cambrian of North Greenland (Conway Morris & Peel 1995) and wiwaxiids from the Burgess Shale (Butterfield 1990) revealed a bilaterian body plan of molluscan-annelid grade (see discussion by Vinther & Nielsen 2005) which contrasts sharply with the presumed fixed-sessile spherical or elongate vase-shaped scleritone in chancellorids (Mehl 1996, 1998; Demidenko 2000; Bengtson & Hou 2001; Janussen et al. 2002; Randell et al. 2005). Butterfield (1990) further demonstrated some fundamental differences between chancellorid and wiwaxiid sclerite morphology. Conway Morris & Chapman (1996, p. 45) indicated that despite similar gross sclerite morphology "comparisons between the articulated scleritomes of halkierids...and chancellorids...suggest at best a remote relationship".

**Chancelloria** Walcott, 1920

*Type species.* *Chancelloria eros* Walcott, 1920.

**Chancelloria cf. eros** (Fig. 4A, F-I)

**Discussion.** The Mount Arrowsmith material consists of internal moulds of isolated sclerites and single rays. Complete sclerites consist of 4+0, 5+0, 6+0, 6+1, 7+1, 8+1 types. Mehl (1998) and Janussen et al. (2002) indicated *C. eros* is characterised by 6-8+1 with rare 4+0 sclerites. The sclerites from the Pinacally Formation are dominated by 6-8+1 (Fig. 4G-I) and occasional 4+0 sclerites. The sclerites also have a flat base, large central basal disc and large circular to weakly ovoid basal pores. The more numerous radial rays are parallel to the body surface. The central ray is perpendicular to the other rays. All these features point to a close similarity with the sclerites of *C. eros* from China and the U.S.A.

*Chancelloria racemifundis* from the Early Cambrian of South Australia (Bengtson in
...or groups of trilobites and, in the way the led a sessile me in denko 2002; further studies of sclerite (1996; sclerite related lids...)

Fig. 4. A, F-I, *Chancelloria* cf. *eros*. All from Pinacally Formation, scale bars 100 μm unless otherwise stated. A, 4 + 0 sclerite, MMMC 4289, sample C1515; B, 7 + 0 sclerite, MMMC 4290, sample C1515; G, 6 + 1 sclerite, MMMC 4293, sample C1417; H, 7 + 1 sclerite, basal view, MMMC 4291, sample C1515, scale bar 500 μm; J, 8 + 1 sclerite, MMMC 4292, sample C1515. B-E, *Archiasterella* cf. *pentactina*. All from Pinacally Formation, scale bars 100 μm. B, 5 + 0 sclerite, MMMC 4296, sample C1515; C, 5 + 0 sclerite, MMMC 4294, sample C1417; D, 5 + 0 sclerite, basal view, MMMC 4297, sample C1515; E, 5 + 0 sclerite, MMMC 4295, sample C1417.

Bengtson *et al*. 1990) and Antarctica (Wrona 2004) and the Middle Cambrian of the Georgina Basin (Mehl 1998) has a comparable range of sclerite types, with a similar number of rays, but can be distinguished by the raised spherulitic structures around the basal foramina and the circular ridge around the basal facet (see Bengtson *et al*. 1990, fig. 25A-D; Wrona 2004, fig. 6T).

**Archiasterella** Sdzuy, 1969

*Type species.* *Archiasterella pentactina* Sdzuy, 1969.

**Archiasterella cf. pentactina** (Fig. 4B-E)

*Description.* Bilaterally symmetrical sclerites (preserved as steinkerns) with central ray absent and 4-5 radiating rays. Median ray recurs towards the centre of the sclerite away from the
basal plane, with four remaining rays relatively straight or weakly curved. Basal foramina relatively large (average 100 μm in diameter) and ovoid in outline.

Discussion. The recurved central ray, bilateral symmetry and taper of all rays suggest an affinity with _A. pentactina_. Brock & Cooper (1993) and Demidenko (in Gravestock _et al._ 2001) describe similar, but more slender sclerites, from the Botoman and Toyonian of South Australia. The poor preservation makes identification difficult.

Phylum & Class UNCERTAIN
Order HYLOITHELMINTHIDA Fisher, 1962
Family HYLOITHELLIDAE Walcott, 1886

Hyolithellus Billings, 1871

Type species. *Hyolithes micans* (Billings, 1871).

Hyolithellus micans* (Billings, 1871) (Fig. 5A-D)

2001 *Hyolithellus micans* (Billings); Demidenko in Gravestock et al. 2001, p. 94, pl. 9, fig. 10 (full synonymy).
2002 *Hyolithellus micans* (Billings); Landing et al., fig. 4.11.
2004 *Hyolithellus micans* (Billings); Wrona, p. 46, fig. 25E.

Description. Fragmentary phosphatic, straight-sided tubes with subcircular cross-section and low angle of taper (less than 5°); maximum length 2.5 mm, maximum width 0.3 mm. External ornament smooth, with occasional, weak annular growth lines. All known tubes are broken at both ends.

Discussion. Bengtson (in Bengtson et al. 1990, p. 186-7) discussed in detail the taxonomic status of the hyolithelmithids, including the type species *H. micans* (Billings). Most species of *Hyolithellus* are discriminated on the nature of the surface sculpture (e.g., Brasier 1984, pp. 236-237; Bengtson et al. 1990, p. 186), but Skovsted (in press) reports a clear gradational series in surface ornament, number and preservation of annulations and degree of tube curvature in large collections of *H. micans* from the Lower Cambrian of Greenland, indicating that only a single biologic species is present. It therefore seems probable that many of the species currently recognised (especially those based on small collections) are probably synonymous with the type species.


Family TORELLELLIDAE Holm, 1893

Torellella Holm, 1893

Type species. *Torellella laevigata* (Linnarsson, 1871).

Torellella laevigata* (Fig. 5K-L)

1871 *Hyolithus laevigatus*; Linnarsson, p. 9, pl. 1, fig. 1.
1988 *Torellella laevigata* (Linnarsson); Landing, p. 690, figs 6.12-6.15, 8.7-8.10 (full synonymy).
1998 *Torellella curvata* Missarzhevsky; Vasilieva, p. 70, pl. 2, fig. 4.
1998 *Torellella latuscula*; Vasilieva, p. 70, pl. 2, figs 8, 10.
1998 *Torellella lentiformis* (Syssoiev); Vasilieva, p. 71, pl. 2, figs 1-3.

Description. Biconvex to weakly flattened, tapering tubes with an oval cross section. Tubes are curved with lateral flanks smoothly rounded. All tubes are broken and no apex has been preserved on any specimen, although the angle of expansion gradually increases towards the adanal end. External surface is smooth with no clear growth lines.

Discussion. The genus *Torellella* has long been a 'catch all' for slender, smooth, curved phosphatic tubes with an elliptical cross-section and simple planar apertures from Cambrian sediments. As noted by Skovsted (in press), species of this genus are difficult to distinguish, but in an attempt to clarify the taxonomy of this group, Landing (1988) synonymised the majority of previously described taxa with the type species, *T. laevigata*. The specimens from the Pinacally Formation are not well preserved but appear to conform with the concept of this species.


Class UNCERTAIN
Order BRADORIIDA Raymond, 1935
Family UNCERTAIN

Mongolitubulus Missarzhevsky, 1977


Discussion. Slender tubiform or spine-shaped fossils with scale-like ornamentation from the Early and Middle Cambrian have traditionally been referred to *Mongolitubulus*. The function and affinities of this taxon have largely been resolved by Skovsted & Peel (2001), Skovsted (2005) and Skovsted et al. (2006, this volume) who have shown that spines referred to *Mongolitubulus* belong to a bradoriid, with multiple spines of different size attached to each valve.
**Mongolitubulus squamifer** Missarzhevsky, 1977 (Fig. 5E-J)


**Description.** Fragmentary, relatively slender phosphatic spines with a maximum length of 2.5 mm and subcircular cross-section. One specimen (Fig. 5J) with compressed, elongate ovoid cross-section. External surface dominated by small (5-10 μm wide) ordered scale-like ornament; some specimens with distinctive blunt tubercles generally arranged in a linear, ordered pattern.

**Discussion.** The regularly spaced, linear, scale-like ornament and blunt tubercles on most specimens from the Pinacly Formation conform closely with specimens referred to *M. squamifer* from the Lower Cambrian of Siberia (Missarzhevsky 1977), North Greenland (Skovsted & Peel 2001, fig. 3C-M), Australia (Ornamented tube Form B of Bengtson et al. 1990, fig. 102A-G) and Antarctica (Wrona 2004, figs 23A-H, 24).

Zhu & Dong (2005, p. 908, fig. 1A) have also described Ornamented Tube Form I from the Middle Cambrian of West Hunan, China that possess an ornament (linear arrangement of raised tubercules or scales) similar to *M. squamifer* from the Pinacly Formation.

The closely related species, *M. henriksenii* Skovsted & Peel (2001) can be distinguished by the presence of a distinctive, widely flared basal (antapical) region of the spines, and more random (chaotic) arrangement of the raised tuberculate ornamentation along the length of the spine (Skovsted & Peel 2001; Skovsted et al. 2006).

It should be noted that Skovsted & Peel (2001, p. 142) have noted a degree of overlap in the ornament on individual spines of both species, making it difficult to assign individual spines with precision to one species or the other.


?Phylum MOLLUSCA Cuvier, 1797
Class HYOLITHA Marek, 1963
Order ORTHOTHECIDA Marek, 1966
Family CIRCOTHECIDAE Missarzhevsky in Rozanov et al., 1969

**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. 6F-H)

2003 *Conotheca cf. C. australiensis* Bengtson in Bengtson et al., 1990; Qian Yi et al., p. 33, pl. 1, figs 6-10.

2000 *Conotheca cf. C. australiensis* Bengtson in Bengtson et al., 1990; Wrona, p. 191, fig. 5A-E.

**Description.** See Bengtson in Bengtson et al. (1990, p. 216); Demidenko in Gravestock et al. (2001, p. 98); and Wrona (2003, p. 191).

**Discussion.** The Pinacly Formation specimens are very fragmentary and consist of internal moulds of straight conchs up to 2 mm in length with circular apertural cross section. Opercula are absent from the collections. The specimens of *C. australiensis* from the Lower Cambrian of South Australia range from being straight to slightly more curved, but are otherwise very similar in overall size and form. The presence of steinkerns and the lack of opercula makes confident assignment difficult. However, the steinkerns from Mount Arrowsmith are identical to the specimens of *Conotheca cf. C. australiensis* described and illustrated by Wrona (2003, p. 191, fig. 5A-E) from Botoman-Toyonian glacial erratic boulders on King George Island, Antarctica. Qian Yi et al. (2001, p. 33, pl. 1, figs 6-10) referred a number of large specimens to *C. cf. australiensis* from the Lower Cambrian (Chiuangchussuan Stage) of south Shaanxi Province, China. As identification is largely based on separate opercula and operculate conchs, their absence in the Pinacly Formation makes definitive assignment very difficult.

**Material.** MMMC 4308-4309 plus 117 specimens (mainly steinkerns) from the Pinacly Formation (samples, 21/9.1A, 21/9.1B, C1515, 21/9.3, 21/9.7A, 21/9.7B, C1417) and the Pimpina Member of the Wydjah Formation (samples 21/9.14, C1510).

Suborder, Superfamily, Family UNCERTAIN

**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 (Fig. 6D-E)

**Discussion.** There are a number of large, generally
poorly preserved straight conchs (many preserved as steinkerns) with an ovoid to subtriangular opercular cross section that develop prominent terraced and slightly undulose transverse growth lines on the exterior surface (or on the inner shell layer). The size, shape and ornament is comparable to Hypiotheca karraculum described from Atadabanian-Toyonian units in South Australia (Bengtson in Bengtson et al. 1990, p. 248, figs 152-155; Brock & Cooper 1993, p. 777, figs 11.13-11.15, 12.1, 12.4; Demidenko in Gravestock et al. 2001, p. 102, pl. 10, figs 3-6). The relatively poor preservation of most specimens (many with iron crusts) and the lack of diagnostic opercula makes taxonomic assignment tentative at this stage.

Material. MMMC 4310, plus 24 fragmentary
specimens from the Pincally Formation (samples, 21/9.1A, 21/9.1B, C1515, 21/9.3, 21/9.7A, 21/9.7B, C1417) and the Pimpira Member of the Wydjah Formation (samples 21/9.14, C1510).

Phylum MOLLUSCA Cuvier, 1797
Class HELCIONELOIDA Peel, 1991
Order PELAGIELLIDA Runnegar & Pojeta, 1985
Family PELAGIELLIDAE Knight, 1952

Pelagiella Matthew, 1895

_Type species._ Cylrotites atlantoides Matthew, 1894.

**Pelagiella madianensis** (Zhou & Xiao, 1984) (Fig. 6i-K)

1977 _Pelagiella lorenzi_ Kobayashi; Zhong, pl. 2, figs 12, 13.

1984 _Auriculataspis conjuncta_; He & Pei in He _et al._, p. 352, pl. 2, figs 10-15, 19, 21.

1984 _Auriculaspis conjuncta_ He & Pei; Zhou & Xiao, p. 135, pl. 4, figs 13-14.

1984 _Auriculaspis madianensis_; Zhou & Xiao, p. 135, pl. 4, figs 15-17.

1986 _Pelagiella_ sp.; Gazdzicki & Wrona, p. 611, fig. 7d.

1987 _Auriculaspis conjuncta_ He & Pei in He _et al._; Yu, p. 274, pl. 67, figs 3-6, 8-11, 15.

1989 _Pelagiella_ sp.; Wrona, p. 540, pl. 10, fig. 4.

1990 _Pelagiella conjuncta_ (He & Pei in He _et al._); Runnegar in Bengtson _et al._, p. 254, figs 168E-K.

1991 _Auriculaspis conjuncta_; He & Pei in He _et al._; Yu & Rong, p. 340, 343, pl. 1, figs 1-9.

1993 _Pelagiella conjuncta_ (He & Pei in He _et al._); Brock & Cooper, p. 780, figs 13.11-13.18.

1994 _Auriculaspis conjuncta_ He & Pei in He _et al._; Feng _et al._, p. 10, pl. 4, figs 1-5, pl. 5, fig. 20, pl. 6, figs 9-10.

2001 _Pelagiella madianensis_ (Zhou & Xiao); Parkhaev in Gravestock _et al._, p. 195, pl. 46, figs 1-12, pl. 47, figs 1-8.

2003 _Pelagiella madianensis_ (Zhou & Xiao); Wrona, p. 206, figs 14C-E.


**Discussion.** The Mount Arrowsmith specimens are preserved as internal moulds, and as discussed by Parkhaev (in Gravestock _et al._ 2001), steinkerns of _P. madianensis_ are very difficult to discriminate from the closely related and largely sympatric species _P. subangulata_ from the Lower Cambrian of South Australia. However, close comparison of figured material from South Australia (Bengtson _et al._ 1990, figs 168E-K; Brock & Cooper 1993, figs 13.11-13.18; Parkhaev in Gravestock _et al._ 2001, pl. 46, figs 1-12, pl. 47, figs 1-8), Antarctica (Wrona 2003, fig. 13C-E) with that here (Fig. 6i-K) shows that mature shells of _P. madianensis_ have a slightly more open coil with a ‘hook-like’ apex and a narrower, less angular apertural outline than _P. subangulata_. Gubanov _et al._ (2004, fig. 7, 6-28) recently described internal moulds of _P. adunca_ Missazhevsky from the Lower Cambrian of Spain that are very similar to _P. madianensis_. Gubanov _et al._ (2004, p. 211) indicated that _P. madianensis_ can be distinguished from _P. adunca_ by its more “elongated aperture and concave spire”, but the illustrations of _P. adunca_ (Gubanov _et al._ 2004, fig. 7.6-7.28) are almost indistinguishable from Australian _P. madianensis_. _Pelagiella primaeva_ (Billings 1872) from the upper Lower Cambrian Browns Pond Formation (illustrated by Landig & Bartowski 1996, fig. 5.19-22) is also very similar to _P. madianensis_ in size, general outline and cross sectional shape.

_Pelagiella madianensis_ is known from Lower Cambrian (Attabanian-Middle Cambrian) strata in South Australia and Lower to early Middle Cambrian strata in China (Parkhaev in Gravestock _et al._ 2001). Wrona (2003, fig. 13C-E) described conspecific steinkerns from late Early Cambrian glaciated erratics on King George Island, Antarctica.

Gravestock _et al._ (2001) recognised _P. madianensis_ as the key taxon of the _P. madianensis_ bizone in the Stansbury Basin and suggested this zone was broadly equivalent to the latest Early Cambrian Toyonian stage.

**Material.** MMMC 4311-4313, plus 27 specimens from the Pincally Formation (samples, 21/9.7A, C1417) and the Pimpira Member of the Wydjah Formation (samples 21/9.14).

Phylum, Class, Order, Family UNCERTAIN

**Genus and species incertae sedis** (Fig. 6A-C)

**Description.** Small planispiral problematic microfossil with swollen spherical basal portion approximately 600 µm wide that spirals through less than half a whorl. Apertural outline ovoid, maximum length 170 µm. Aperture with distinct rim. External ornament consists of a series of closely interlocking low, approximately star-shaped ossicles or sclerites.
**Discussion.** Only two specimens of this enigmatic shell have been recovered from low in the Pinocaly Formation. The affinities of these shells is problematic. The planispiral form is reminiscent of some univalve helcionelloid taxa such as *Protowenella* (see Brock 1998), but all known specimens of *Protowenella* are preserved as steinkerns and the original shell is assumed to have been calcitic. The specimens from the Pinacaly Formation appear to have a phasphatic composition. The authors know of no comparable forms and the affinities of this shell must remain problematic until more specimens are recovered.

**Material.** MMMC 4314, plus 1 other specimen from the Pinacaly Formation (sample 21/9.1B).

Phylum BRACHIPODA Dumeril, 1806
Subphylum LINGULIFORMEA Williams, Carlson, Bruton, Holmer & Popov, 1996
Class LINGULATA Goryansky & Popov, 1985
Order LINGULIDA Waagen, 1885
Superfamily LINGULOIDEA Menke, 1828
Family EOOBOLIDAE Holmer, Popov & Wrona, 1996

**Eooebulus Matthew, 1902**


**Discussion.** The fragmentary nature of the specimens and the lack of complete ventral valves precludes a more precise taxonomic assignment at this stage. The dorsal valves of *Eooebulus* sp. are similar to the taxon originally described as *E. aff. elatus* from the Toyonian of South Australia (Brock & Cooper 1993; Holmer et al. 1996; Ushtinskaya & Holmer in Gravestock et al. 2001) and Antarctica (Holmer et al. 1996). Skovsted & Holmer (2005, p. 330) have recently suggested *E. aff. elatus* should be considered a junior subjective synonym of *E. priscus* (Poulsen) from the Lower Cambrian of north-east Greenland. *Eooebulus* sp. is almost indistinguishable from *E. priscus* in terms of size, outline and external ornament, but the dorsal valve interior of *Eooebulus* sp. displays a much more prominent median ridge and the pseudointerarea has a more distinctive m-shaped anterior margin and better defined median depression and propareas than in *E. priscus* (see Skovsted & Holmer 2005, pl. 2, figs 6, 10; pl. 3, figs 4-5, 7-8, 10-11; Ushtinskaya & Holmer in Gravestock et al. 2001, pl. 17, figs 6, 10, 12). In addition, the fragments of recovered ventral valves of *Eooebulus* sp. have a considerably longer and narrower pedicle notch (Fig. 7D) than in *E. priscus*.

The anterior margin of the dorsal valve pseudointerarea is distinctly m-shaped and presence of a well developed low, broad median ridge that extends to at least 50% shell length is very similar to the dorsal valve interior of *Lingulella bynguanoensis* described by Roberts in Roberts & Jell (1990, p. 302, fig. 35) from the Ordian-early Templetanian Coonigan Formation in western N.S.W. The type specimen of *L. bynguanoensis* (see Roberts & Jell 1990, fig. 35A) is a ventral valve which is considerably larger, more complete and more elongate than any specimens of *Eooebulus* sp. indet. from...
the Mount Arrowsmith area. However, whilst Roberts & Jell (1990) note that the collection of *L. bynguanoensis* is dominated by narrow, elongate shells, there is a gradation in shell outline to a more subrounded shell form that is more similar to the Mount Arrowsmith specimens. Compare for example, dorsal valves of *Eoobolus* sp. (Fig. 7A-B, E-F) with subrounded dorsal valves of *L. bynguanoensis* (Roberts & Jell 1990, fig. 35E, H-I). Roberts & Jell (1990) make no mention of a pustulose post larval shell ornament in *L. bynguanoensis*, though they do mention that many specimens have a distinctive “orange-brown stain” and this could conceivably mask any finely pustulose ornament. Detailed SEM examination of the type material is required to confirm the presence (or otherwise) of a pustulose postlarval shell in *L. bynguanoensis*, which would necessitate the Coonigan species being transferred to *Eoobolus*, and the Mount Arrowsmith material regarded as conspecific.

Krus (1998, p. 31, fig. 28A-J) also described elongate forms of *L. cf. bynguanoensis* from Ordian-Templetionian successions in the western Georgina, Wiso and Daly basins of the Northern Territory. Apart from being more elongate, the dorsal valves of these forms also lack the characteristic median ridges of *L. bynguanoensis*. These specimens appear more comparable with *E. priscus* from Botomal and Toyonian equivalent successions in South Australia (Brock & Cooper 1993; Ushatinskaya & Holmer in Gravestock et
al. 2001) and Antarctica (Holmer et al. 1996).

**Material.** MMMC 4315-4321, plus 30 dorsal valves and 4 ventral valves from the Pincally Formation (samples 21/9.1A, 21/9.1B, C1515, C1417, 21/9.7A, C1516) and 11 dorsal valves from the Pimpina Member of the Wydjah Formation (samples 21/9.18, C1513).

Superfamily ACROTHELIOIDEA Walcott & Schuchert, 1908 (in Walcott, 1908)
Family ACROTHELIDAE Walcott & Schuchert, 1908 (in Walcott, 1908)
Subfamily ACROTHELINAE Walcott & Schuchert, 1908 (in Walcott, 1908)

**Eothele** Rowell, 1980

**Type species.** *Acrothele spurri* (Walcott, 1908).

**Discussion.** Holmer et al. (1996) separated the acrothelid genus *Eothele* from the morphologically similar *bottfordiid* *Karathele* based largely on the fact that the delthyrium in *Karathele* remains open throughout ontogeny whereas the delthyrium in *Eothele* gradually closes over ventrally, producing an elongately ovoid or keyhole-shaped foramen. The taxon *Eothele nauru* described by Kruse (1990, 1991, 1998) from the Ordian-early Templetonian Tindall Limestone in the Daly, Georgina and Wiso basins of the Northern Territory, subsequently described from the Toyonian Wirrealpa Limestone in South Australia (Brock & Cooper 1993), was transferred to *Karathele* by Holmer et al. (1996) because of the persistent open delthyrium.

Rowell’s (1980, p. 17) diagnosis of *Eothele* focusses on the flexure of the commissure and overall shape of the valves, though the description of the type species, *E. spurri* from the Pioche Shale in Nevada notes the presence of an elongate subtriangular external pedicle foramen which continues internally as a “very short subcylindrical tube”.

**Eothele granulata** Roberts in Roberts & Jell, 1990 (Figs 8A-I; 10M-N)

1990 *Eothele granulata*; Roberts in Roberts & Jell, 1990, p. 293, fig. 28A-P.

**Description.** See Roberts (in Roberts & Jell 1990, p. 293, 295) for detailed description.

**Discussion.** The Mount Arrowsmith material is mainly dominated by ventral valves, and the completely enclosed, elongate pedicle foramen with short, tear-drop shaped pedicle tube along with the pustulose external ornament and well developed thickened posterior platform on the interior of the shell accord exactly with *E. granulata* Roberts (Fig. 8A, I). As with the material described by Roberts in Roberts & Jell (1990) from the Coonigan Formation, juvenile ventral valves from Mount Arrowsmith also display a well developed open slit-like delthyrium (Fig. 10M,N) that gradually closes over in larger, rounder, more mature shells. The Coonigan specimens appear to have more of a “keyhole” shape to the internal pedicle tube (Roberts & Jell, fig. 28K) compared to the more pyriform shape of the pedicle tube in the Mount Arrowsmith specimens (Fig. 8D-F, I).

Another slight difference between the Coonigan specimens and the Mount Arrowsmith material is that the former are described as possessing “low, rounded, variable radial ribs” (Roberts in Roberts & Jell 1990, p. 293). These features are completely absent in the Mount Arrowsmith specimens.

The type species, *E. spurri*, is very close to *E. granulata* but tends to have a higher ventral pseudointerarea and greater shell flexure. The interior of *E. spurri* is not well known and Rowell (1980) makes no mention of the pair of distinct posterior depressions and thickened platform that dominates the interior of ventral valves of *E. granulata* (Fig 8D, I). The poorly known *E. tubulus* described by Ushatinskaya (in Voronova et al. 1987) from the Lower Cambrian of the Mackenzie Mountains, Canada can be discriminated by its circular pedicle foramen, narrower internal pedicle tube and more prominent internal propareas.

Kruse (1998) observed that in Australia, at least, species of *Karathele* occupied shallow water cratonic seas in the Early-Middle Cambrian, whereas *Eothele* dominated habitats associated with the palaeo-Pacific shelf margin. The presence of *E. granulata* from Mount Arrowsmith lends further support to this observation.


**Acrotheloid gen. & sp. indet.** (Fig. 8J-K)

**Discussion.** A few fragmentary dorsal valves characterised by a distinctive, closely spaced concentric ornament, display interiorly a well developed triangular median plate raised above the valve floor that merges laterally with well developed, rounded propareas. No discernable muscle scars are preserved. Interestingly, this
Fig. 8. A-I, *Eothele granulata* Roberts. Scale bars 100 μm unless otherwise indicated. A, ventral valve exterior, MMNC 4322, Pincaley Formation sample C1515; B, magnification of ventral slit-like foramen, MMNC 4323, Pincaley Formation sample C1515; C, ventral valve exterior, scale bar = 1 mm, MMNC 4326, Pincaley Formation sample 21/9.7B; D, ventral valve interior, scale bar = 1 mm, MMNC 4324, Pincaley Formation sample C1515; E-F, ventral valve interior and close up of pedicle tube, scale bar in E = 1 mm, MMNC 4327, Pincaley Formation sample 21/9.1B; G-H, ventral valve exterior and magnification of foramen, scale bar in G = 1 mm, MMNC 4328, Pincaley Formation sample 21/9.1B; I, ventral valve interior showing muscle scars, MMNC 4325, Pincaley Formation sample C1515. J-K, Acrotheloid gen. & sp. indet., dorsal valve exterior and interior, scale bar in J & K = 1 mm, MMNC 4331, Pimpina Member of the Wyndham Formation sample C1510.
taxon seems to be conspecific with the dorsal valves identified and illustrated by Kruse (1998, fig. 31-J-K) as "acrotheloid indet." from the Gum Ridge Formation in the western Georgina Basin. All fragmentary material of this taxon is derived from the Wydjah Formation, but the lack of complete specimens precludes formal taxonomic identification at this stage.

Material. MMHC 4331, plus a few shell fragments from the Pimpria Member of the Wydjah Formation (sample C1510).

Order ACROCRETIDA Kuhn, 1949
Superfamily ACROCRETIOIDEA Schuchert, 1893
Family ACROCRETIDAE Schuchert, 1893

Prototreta Bell, 1938

Type species. Prototreta trapeza Bell, 1938, by original designation.

Discussion. The concept of the genus Prototreta was discussed in some detail by Popov et al. (1996). These authors noted that Prototreta is probably represented by a plexus of three species groups that can be discriminated on the nature of the median septum in the dorsal valve. One group, based on the type species of Prototreta, P. trapeza Bell, 1938 as well as P. flabellum Bell, 1941 from the Middle Cambrian of Montana, is characterised by a well developed digitate median septum. The second group has a more blade-like median septum, sometimes with septal rods present. This group has been referred to the genus Homotreta by some authors with P. interrupta as the type (see discussion below). The third group is characterised by a high, triangular median septum with a flat, narrow surmounting plate. The material from Mount Arrowsmith can be confidently placed in the first of these species groups, with close similarity to the type species, P. trapeza Bell.

There are very few Lower Cambrian or early Middle Cambrian acrocretoids with a complex digitate median septum in the dorsal valve. The genus Anguloarea, first described from the Middle Cambrian of Texas by Palmer (1954) is similar to Prototreta in having a digitate median septum, but can be discriminated by (1) having the foramen in the ventral valve completely enclosed within the larval shell, (2) a more prominent apical process in the ventral valve and (3) deeper, more posteriorly positioned apical pits (see Holmer & Popov 2000, p. 104).

The genus Homotreta Bell has traditionally been considered a junior subjective synonym of Prototreta (Rowell 1965; Zell & Rowell 1988; Holmer & Popov 2000). However, Pelman (1973, 1977) recognised Homotreta as a valid taxon group, based on the type H. interrupta Bell and a number of Lower and Middle Cambrian forms from Siberia, that differ from Prototreta by having a shorter and less well developed dorsal pseudointerarea and a shorter and more simple, blade-like median septum (see Holmer et al. 2001, p. 95). Prototreta millisi n. sp. from the Pincaley and Wydjah formations represents the first record of the genus from Australia.

Prototreta millisi n. sp. (Figs 9A-M, 10A-E)

Etymology. In honour of Dr. Kingsley Mills, Geological Survey of N.S.W., for his major contribution to our understanding of the geology of the Koonenberry Belt.

Diagnosis. High conical ventral valve with dominantly procline pseudointerarea; dorsal valve interior with high, narrow median septum with 2-12 prominent digitate processes developed in both the dorso-ventral and lateral plane at the anterior periphery of the septum. Median septum occupies 70-90% valve length.

Description. Shell strongly ventribiconvex with subcircular outline. Ventral valve is high and subconical, with maximum height at the apex. Ventral pseudointerarea slightly convex ranging from procline (dominant) to catacline, divided medially by a relatively shallow intertrough that widens from the apex towards the valve margin. Foramen circular (50 μm in diameter) not completely enclosed within the larval shell. External surface with subdual concentric ornament, with occasional drapes and nicks points. Dorsal valve weakly but evenly convex with very shallow, anteriorly widening sinus. Pseudointerarea low, narrow, anacrine, occupying approximately 45% total valve width. Propareas narrow with shallow median plate. Ornament as in ventral valve.

Ventral valve interior with short pedicle tube, supported by a relatively low apical process (possibly preservational) and low boss-like muscle platform. Dorsal valve median septum high, narrow and triangular in lateral view, with 2-12 digitate processes developed in both the dorsoventral and lateral plane at the anterior periphery of the septum. Septum originates directly under pseudointerarea and extends to between 70-90% valve length. Cardinal muscle scars generally poorly preserved, but some specimens have large, broadly subovoid scars.
Fig. 9. *Prototreta millsii* n. sp. Scale bars 100 μm. A-B, lateral and posterior view of ventral valve, MMMC 4332, Pinacally Formation sample C1417; C, interior of ventral valve, MMMC 4333, Pinacally Formation sample C1417; D, exterior of fragmentary ventral valve, MMMC 4334, Pinacally Formation sample C1417; E, I, exterior and interior of ventral valve, MMMC 4335, Pinacally Formation sample C1515; (continued opposite)
Discussion. The well developed digitate median septum in the dorsal valve of *Prototreta milisi* n. sp. (Figs 9K-M, 10B, C, E) clearly suggests an affinity with the "digitate" species group represented by the type species *P. trapeza* Bell, 1938 from the Middle Cambrian of the USA. *P. trapeza* (Bell 1941, pl. 31, figs 34-48) can be distinguished from *P. milisi* by its dominantly cataclinal, straighter ventral pseudointerarea with deeper intertongue and a dorsal valve with broader, better developed propropores and generally wider median septum. The maximum width of the valve is anterior of the midlength in *P. trapeza*, but is close to the midlength in *P. milisi* (Fig. 9K). In general, the median septum in *P. trapeza* is more digitate than in *P. milisi*, though some fragmentary specimens from the Pinacally Formation display a well developed digitate median septum with a flattened ventral surface that approaches that of *P. trapeza* (e.g. Fig. 10C). *Prototreta flabellata* Bell from the Middle Cambrian of Montana, USA can be distinguished by its characteristic ‘criss-crossed’ or crinkled external ornament along the midline of the anterior slope of the dorsal sulcus (see Bell 1941, pl. 31, figs 53, 55, 57). Internal details of *P. flabellata* are poorly known, so far comparison to *P. milisi* is impossible at present. *Prototreta attenuata* (Meek) from the Middle Cambrian of Utah (Holmer & Popov 2000, fig. 61, 2a-h) is also similar in overall form to *P. milisi*, but the dorsal valve is lower and the digitate processes rise more abruptly at the anterior end of the septum.

*Prototreta venusta* Koveva, from the early Middle Cambrian of Kazakhstan, has a lower conical ventral valve and a more transverse dorsal valve with a shorter median septum (reaching only 70% valve length) that is composed of one or two short, blunt-ended septal rods (see Holmer et al. 2001, pl. 30, figs 15-17, pl. 32, figs 1-11). *Prototreta convexusa* Aksarina (in Aksarina & Pelman 1978, p. 61, pl. 2, figs 1-17), from the Lower Cambrian of Siberia, has a deeper, more convex dorsal valve with a more prominent median plate and a higher median septum that is terminated at the anterior end by three delicate spines.

Material. MMMC 4332-4345, Holotype MMMC 4337, plus 10 dorsal valves and 18 ventral valves from the Pinacally Formation (samples 219.9.A, C1515, 219.9.3, 219.9.7A, C1417, C1516) and 5 dorsal valves from the Pimpira Member of the Wydjah Formation (sample 219.9.18).

Class PATERINATA Williams, Carlson, Bruton, Holmer & Popov, 1996
Order PATERINIDA Rowell, 1965
Superfamily PATERINOIDEA Schuchert, 1893
Family PATERINIDAE Schuchert, 1893

**Micromitra** Meek, 1873

**Type species.** *Iphidea scuptilis* (Meek, 1873).

**Micromitra nerranubawu** Kruse, 1990 (Fig. 10F-L, O)

1990 *Micromitra nerranubawu*; Kruse, pp. 35-36, pl. 13, figs A-J, pl. 14, figs A-F (cum. syn.)
1990 *Micromitra nerranubawu* Kruse; Roberts in Roberts & Jell, p. 297, figs. 30-31.
1991 *Micromitra nerranubawu* Kruse; Kruse, p. 179, fig. 7F-H.
1998 *Micromitra nerranubawu* Kruse; Kruse, p. 41, fig. 35.

**Description.** See Kruse (1990, pp. 35-36) and Roberts in Roberts & Jell (1990, pp. 297-298) for complete description.

**Discussion.** Whilst there are relatively few specimens of this form in the Mount Arrowsmith material, the relatively large, flaring homoeoeldidium with reduced delthyrial ridges and closely spaced undulose concentric ornament is characteristic of this species. Its presence in the Pinacally and Wydjah Formations provides further correlation with the Coonigan Formation (Roberts & Jell 1990) and the Daly, western Georgina and Wiso basins in the Northern Territory (Kruse 1990, 1998). Brachial valves are rare in the current collection (Fig. 100), but a number of large specimens with an almost straight posterior margin and a finely pustulose external ornament overprinted on closely spaced concentric growth lines are present; these are probably best interpreted as gerontic specimens of *M. nerranubawu*.

Material. MMMC 4346-4347, plus 6 dorsal valves and 5 ventral valves from the Pinacally Formation
Fig. 10. A-E, *Protostreta millsi* n. sp. Scale bars 100 μm. A, D, lateral and posterior view of MMMC 4342 (Fig. 9K), Pinckley Formation sample C1516; B, lateral view of dorsal valve median septum, MMMC 4343, Pinckley Formation sample C1516; C, digitate median septum, MMMC 4344, Pinckley Formation sample C1516; E, fragmentary dorsal valve interior, MMMC 4345, Pinckley Formation sample C1516. (continued opposite)
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