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Late Cambrian trilobites from the Dolodrook River limestones, eastern Victoria, Australia

JOHN R. PATERSON and JOHN R. LAURIE


An early Late Cambrian (late Mindyallan-Idamean) trilobite fauna is described from limestone bodies in the Dolodrook River area, eastern Victoria. Seven taxa are referred to previously described species: Inimitagnostus ineptus (Kobayashi, 1938), Pseudagnostus idaï Opik, 1967, Corynecorynus plumula Whitehouse, 1939, Rhyssometopus thielei (Chapman, 1911), Eugonocarps tessellatum Whitehouse, 1939, Protanmites magnificus Shergold & Webers, 1992 and Meteoraspis etheridgei (Chapman, 1911), seven taxa are left under open nomenclature: Idolagnostus ?agrestitis Opik, 1967, Peragnostus aff. invalidus (Lu & Lin, 1989), Ammagnostus sp., Tomagnostella sp., Pterocephaliid? gen. et sp. indet., Tsiananid gen. et sp. indet. 1 and Tsiananid gen. et sp. indet. 2, and one represents a new species: Mindycrusta oepiki sp. nov. Protanmites Whitehouse, 1939 is considered to be a senior subjective synonym of Prismenaspis Henderson, 1976a. Two trilobite assemblages are recognised: the Protanmites Assemblage and the Mindycrusta Assemblage. The Protanmites Assemblage is interpreted as representing an autochthonous assemblage inhabiting a moderate to high energy, inner shelf (peritidal) environment. The Mindycrusta Assemblage represents a paraautochthonous assemblage inhabiting a low to moderate energy, open ocean-facing, outer shelf to upper slope environment.

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ADVANCES in the study of Cambrian trilobites of Victoria were made near the turn of the last century with the earliest publication by Etheridge (1896) describing the Middle Cambrian corynecorynid Dinesis ica from the Knowsley East Shale in the Heathcote Greenstone Belt. Subsequent publications on the Middle Cambrian trilobites from the Knowsley East Shale include Gregory (1903), Chapman (1917) and Opik (1949) – a summary of the trilobite fauna is given by Thomas & Singleton (1956), Edwards et al. (1998) and Warne et al. (2003).

The first investigation of Cambrian trilobites from the limestone bodies in the Dolodrook River area was conducted by Chapman (1908) who suggested that the limestones were possibly of Upper Ordovician age, based on preliminary identifications and limited knowledge of the geology. However, in Chapman’s (1911) subsequent publication describing the trilobites from this area, he advocated an Upper Cambrian age. Singleton (in Harris & Thomas 1954, p. 36) provided a list of trilobites from the limestones cropping out along the Dolodrook River (upstream from Black Soil Gully) and at Roan Horse Gully, and regarded the fauna as a whole to be latest Middle Cambrian in age (see also Thomas & Singleton 1956, p. 158). Several species recognised by Singleton represent those described by Chapman (1911), but the majority were reassigned to different genera. Unfortunately, Singleton erected a new generic name, Thielaspis, for those species previously assigned to Psychoparia by Chapman (1911), but did not nominate a type species nor provide a formal description or illustrations. Therefore, in failing to conform to Article 13 of the ICZN (Ride et al. 1985), the generic name Thielaspis should be considered nomen nudum (see Jell & Adrain 2003, p. 483). Opik (1967, p. 32) assigned the Dolodrook faunas to the Mindyallan and Idamean stages based on the faunal list given by Thomas & Singleton (1956). Recently, A. R. Palmer (pers. comm. in Brock & Talent 1999, p. 110) provided information on the
trilobites from the Dolodrook limestones based on a re-evaluation in 1961 of the taxa listed in Thomas & Singleton (1956). Palmer recognised three distinct faunas - the oldest fauna from Garvey Gully being Middle Cambrian in age, the second representing an upper Mindyallan fauna, and the youngest fauna from Roan Horse Gully indicating a basal Idamean (Late Cambrian) age.

This paper represents a taxonomic revision of the Cambrian trilobites from the Dolodrook River area, documenting extensive collections made by Laurie from four of the major limestone bodies. This revision of the trilobite fauna has allowed for better age constraints on the Dolodrook limestone deposits. Relative abundance data on trilobite species and associated sedimentological evidence from each locality has enabled recognition of depth-related faunal assemblages.

**GEOLOGICAL SETTING**

Fossiliferous Cambrian deposits in Victoria are restricted to the NW-SE-trending Heathcote and Mt Wellington Greenstone Belts, defining the western and eastern margins respectively of the Melbourne Zone in the southwestern Lachlan Fold Belt (Crawford 1988; Glen 1992; Brock & Talent 1999; Warne et al. 2003). The Dolodrook River Inlier, representing part of the Mt Wellington Greenstone Belt (Fig. 1), is a broad NW-SE striking, anticlinal structure with a core of serpentinised ultramafic rocks known as the Thiele Igeous Complex (Crawford et al. 1984; Nelson et al. 1984; Crawford & Keays 1987; Crawford 1988; VandenBerg et al. 2000; Spaggiari et al. 2003).

The serpentinised intrusions of the Thiele Igeous Complex are unconformably overlain by the Garvey Gully Formation. This unit is 200 m thick and consists of fine to medium-grained, poorly sorted green to grey volcanogenic sandstone and mudstone, with minor interbedded conglomerate, limestone and shale, and has been interpreted as representing a turbidite deposit (Duddy 1974; Brock & Talent 1999; VandenBerg et al. 2000; Crawford et al. 2003; Spaggiari et al. 2003).

The Dolodrook River limestones occur as a
series of fault-bounded limestone bodies within the Garvey Gully Formation. Previous studies (Teale 1920; Duddy 1974; VandenBerg 1988; Crawford 1988; Spaggiari et al. 2003) have regarded the Dolodrook River limestones as an autochthonous unit within the Garvey Gully Formation. VandenBerg (1988) and VandenBerg et al. (2000) have thus considered the Dolodrook River limestones to represent a formal lithostratigraphic member of the Garvey Gully Formation; i.e., the Dolodrook Limestone Member. However, Brock & Talent (1999) have suggested that the Garvey Gully Formation is mid-Ordovician (Darriwilian) rather than Cambrian in age, based on the occurrence of the graptolites Diplagnostus and Didymagnostus, and therefore the Dolodrook River limestones do not constitute a coherent stratigraphic unit within it. In light of this apparent age discrepancy, Brock & Talent (1999) interpreted the Dolodrook River limestones as representing olistoliths derived from cannibalisation of a shallow-water carbonate platform deposited in a turbiditic environment (the Garvey Gully Formation). Furthermore, Brock & Talent (1999) noted that the trilobite faunas from the Dolodrook River limestones represent three distinct ages (discussed above), suggesting a history of episodic platform collapse or perhaps reflecting the history of incision into deeper and older horizons on a ‘lost’ carbonate platform. Revision of the trilobite fauna from the Dolodrook River limestones herein indicates the presence of only two assemblages, suggesting that perhaps the limestone bodies represent different facies of the same carbonate platform. Palaeontological and sedimentological evidence (discussed below) suggests that the limestone bodies (D-RH and D-UCM) in the southeast portion of the Dolodrook River Inlier represent a shallow marine (inner shelf) environment, and limestone bodies to the northwest (D-GG and D-BSW) represent a deeper water (outer shelf to slope) environment. The apparent facies trend along strike of the Dolodrook River Inlier suggests that perhaps the limestone bodies are in situ or autochthonous, representing fault blocks within the anticlinal structure of the Dolodrook River Inlier, and that the limestones are small inliers protruding through the mid-Ordovician Garvey Gully Formation. Unfortunately, field relations between units are difficult to determine in the Dolodrook River area due to a paucity of outcrop and extensive alluvial cover, thus no firm conclusions can be drawn at present.

The Dolodrook River limestones are represented by eleven limestone outcrops (Brock & Talent 1999). Trilobites were sampled from four of the limestone bodies (Fig. 1), [grid references refer to the 1:25 000 Tali Kargn topographic sheet, 1st edn, 1990]: (1) Roan Horse Gully (D-RH), situated on the western flank of Roan Horse Gully at 768418; (2) D-UCM is located uphill southwards from the abandoned chromite mine at 762419; (3) Garvey Gully (D-GG), situated on the southwestern flank of Garvey Gully at 732439; and (4) west of Black Soil Gully (D-BSW), adjacent to the Dolodrook River at 725445. It is important to note here that trilobites from D-GG and D-UCM were sampled from several parts of the limestone bodies at these localities, and have been labelled accordingly: D-GG1, D-GG2, D-GG3, D-GG4, D-UCM1 and D-UCM13.8. Trilobites from D-RH and D-BSW were obtained from a single sample at each locality (D-RH5 and D-BSW1 respectively).

**AGE AND CORRELATION**

Trilobites from the Dolodrook River limestones have closest affinities with those of western Queensland described by Whitehouse (1939), Ópik (1967), Shergold (1982) and Henderson (1976a). Close faunal similarities are also evident in Late Cambrian faunas from western New South Wales (Powell et al. 1982), Northern Victoria Land (Cooper et al. 1996) and the Ellsworth Mountains (Soloviev et al. 1984; Shergold & Webers 1992) in Antarctica, northwestern Hunan, South China (Peng 1992; Peng & Robison 2000; Peng et al. 2001a, b), and the Malay Karatau, Kazakhstan (Ergaliev 1980).

Trilobites from the Dolodrook River limestones indicate an early Late Cambrian (late Mindyallan-Idamean) age. It is uncertain whether all of the limestone bodies from the Dolodrook River area are contemporaneous. However, limestones from D-RH and D-UCM appear to be coeval, as is the case for D-GG and D-BSW, based on the apparent homogeneity in faunal composition between those pairs of localities (listed below; see also Trilobite assemblages and related palaeoenvironments). Age determinations are based primarily on agnostid biozonation, although polymers are also considered. Of the polymers, only Eugonocare tessellatum and Protenmites magnificans are age-diagnostic taxa. The other polymers are species endemic to the region or have been left under open nomenclature. The exception is Corynexochus plumula, which, despite being a widespread species, it is of limited use biostratigraphically because it is temporally long-ranging, spanning the Glyptagnostus reticulatus Zone to the earliest Iverian (Irvignella tropica Zone equivalent) (see Peng 1992; Pratt 1992). The age of the Dolodrook trilobite assemblages is discussed in terms of the northern Australian Cambrian stages and zones sensu Shergold (1997) and Geyer & Shergold (2000); a
Cambrian correlation chart showing the biostratigraphic scheme for Australia and other relevant areas is illustrated in Figure 2.

Trilobite assemblages from the four Dolodrook River limestone localities comprise the following taxa:


D-UCM: *Pseudagnostus idalis* (D-UCM1); *Protemmites magnificans* (D-UCM1); Tsianiiid gen. et sp. indet. 2 (D-UCM13.8).

D-GG: *Innagnostus inexpectans* (D-GG1); *Pseudagnostus idalis* (D-GG2, 3); *Peragnostus aff. invalidus* (D-GG1); *Corynexochus plumula*

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**Fig. 2.** Cambrian correlation chart for Australia, South China and Laurentia; modified from Geyer & Shergold (2000, table 1). Note that the base of the Ordovician for Laurentia is placed below the now internationally agreed Cambro-Ordovician boundary (Cooper et al. 2001).
(D-GG2); Eugonocare tessellatum (D-GG1, 2, 3); Meteoraspis etheridgei (D-GG4); Mindycrusta oepli (D-GG1, 2, 3, 4).

D-BSW: Ininitagnostus inexpectans; Idolagnostus *agrestis*; Ammagnostus sp.; Tomagnostella sp.; Corynexochus plumula; Eugonocare tessellatum; Mindycrusta oepli; Rhysometopus theilei; Tsinaniid gen. et sp. indet. 1.

Locality D-RH

Protemnites magnificans was recorded from the Minaret Formation at Springer Peak in the Heritage Range, Ellsworth Mountains, West Antarctica by Shergold & Webers (1992). They correlated the trilobite faunal assemblage from the Minaret Formation (containing *P. magnificans*) with the Australian late Idamean zones of *Erixanium sentum* and *Stigmatoa diloma*, and with the Dunderbergia Zone (late Dresbachian) of North America. This correlation is further supported by the occurrence of *Pseudagnostus cf. vastules* in the Minaret Formation. Powell et al. (1982) documented *Prismenaspis?* sp. nov. (tentatively considered herein to be synonymous with *Protemnites magnificans*), from the Cupala Creek Formation in northwestern New South Wales. The associated occurrence of *Stigmatoa rysoni* and *Pseudagnostus idalis* (sensu lato) in the Cupala Creek Formation indicates a range through the entire Idamean, from the *Glyptagnostus reticulatus* Zone to the *Stigmatoa diloma* Zone.

Locality D-UCM

This locality contains only a single agnostoid species, *Pseudagnostus idalis*. This species ranges through the entire Idamean stage, from the *Glyptagnostus reticulatus* Zone to the *Stigmatoa diloma* Zone of western Queensland (Shergold 1982). The co-occurrence of *Protemnites magnificans* supports an Idamean age.

Locality D-GG

Ininitagnostus inexpectans has been recorded in Australia from the *Glyptagnostus reticulatus* and *Proceratopyge cryptica* Zones (Öpik 1967; Shergold 1982). It is known from the *Glyptagnostus stolidotus* and *Glyptagnostus reticulatus* Zones in China (Peng 1992; Peng & Robison 2000).

Tomagnostella? *invalida* Lu & Lin, 1989, was originally recorded from the *Pseudoglyptagnostus clavatus-Sinoproceratopyge kiangshaniensis* Zone of western Zhejiang. This correlates with the *Irvingella tropica* Zone of western Queensland according to Peng (1992). *Peragnostus cf. invalidus* has been recorded from the Cili-Taoyuan area of Hunan by Peng (1992) as coming from the *Corynexochus plumula-Sinoproceratopyge cf. kiangshaniensis* Zone up to the *Agnostotes (Pseudoglyptagnostus) clavatus-Irvingella angustilimbata* Zone; the latter zone correlates with the *Pseudoglyptagnostus clavatus-Sinoproceratopyge kiangshaniensis* Zone of western Zhejiang. According to Peng (1992) these correlate with the *Erixanium sentum, Stigmatoa diloma* and *Irvingella tropica* Zones of western Queensland. These data suggest correlation with the late Idamean, but since the relationship of the illustrated specimen to *P. cf. invalidus* is somewhat obscure, little credence can be placed on direct correlation.

As mentioned above, *Pseudagnostus idalis* ranges through the entire Idamean stage of western Queensland (Shergold 1982).

Eugonocare tessellatum has been recorded from the Georgina Limestone (Henderson 1976a, b) and the Pomegranate Limestone (Shergold 1982) in western Queensland. Both of these occurrences are from measured stratigraphic sections, in the *Stigmatoa diloma* Zone and indicate a latest Idamean age. Shergold (1982) also noted its occurrence in the *Irvingella tropica* Zone, which is basal Iverian in age.

Locality D-BSW

Agnostoids give a strong indication that locality D-BSW is unlikely to be any younger than *Proceratopyge cryptica* Zone in age. *Idalagnostus agrestis* was first recorded from the *Glyptagnostus stolidotus* Zone of western Queensland by Öpik (1967), although its probable synonym, *I. dryas*, is known from the latter part of the *Lejopyge laevigata* Zone to the *Glyptagnostus stolidotus* Zone. However, the genus is poorly known and has been recorded as high as the *Stigmatoa diloma* Zone (Shergold 1982).

Tomagnostella has only been recorded as high as the upper parts of the *Lejopyge laevigata* Zone in Australia (Öpik 1967), but in China it is found as late as the *Glyptagnostus stolidotus* Zone (Peng & Robison 2000).

Ammagnostus extends up into the *Glyptagnostus stolidotus* Zone in western Queensland (Öpik 1967) and has a similar upper extent in China (Peng & Robison 2000).

The range of *Ininitagnostus inexpectans* (mentioned above) supports the late Mindyallan-early Idamean age determination for locality D-BSW. However, the co-occurrence of *Eugonocare tessellatum*, (also evident at D-GG1, see faunal list above), suggests either that the faunal extends up to the *Stigmatoa diloma* Zone, or that the range of *E. tessellatum* extends down to the early Idamean *G. reticulatus* zone. Despite the
**Table 1.** Sedimentology of the Dolodrock River limestones.

<table>
<thead>
<tr>
<th>Locality</th>
<th>D-RH</th>
<th>D-UCM</th>
<th>D-GG</th>
<th>D-BSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithology</td>
<td>Predominantly grainstones with minor packstones</td>
<td>Grainstones &amp; packstones</td>
<td>Grainstones, packstones, wackestones; minor mudstones (graded bedding present)</td>
<td>Predominantly packstones &amp; wackestones, with minor grainstones &amp; mudstones (graded bedding present)</td>
</tr>
<tr>
<td>Non-skeletal allochems</td>
<td>Oncolites abundant; algal pellets; ooids common; minor intraclasts</td>
<td>Minor algal pellets; ooids common; minor micritic intraclasts</td>
<td>Minor pellets; minor intraclasts</td>
<td>Minor intraclasts</td>
</tr>
<tr>
<td>Skeletal allochems</td>
<td>Trilobites; Roanella platystrophioiides (articulated brachiopods); Lingulate brachiopods; crinoids; sponges; gastropods</td>
<td>Trilobites; Roanella platystrophioiides (articulated brachiopods); Lingulate brachiopods; crinoids; sponges; gastropods</td>
<td>Trilobites; lingulate brachiopods; echinoderms; molluscs (minor)</td>
<td>Trilobites; lingulate brachiopods; echinoderms</td>
</tr>
<tr>
<td>Trilobite cuticle thickness</td>
<td>Predominantly thick (200-350µm) with less common thin cuticle (70-140 µm)</td>
<td>Predominantly thick (170-350µm) with less common thin cuticle (70-100 µm)</td>
<td>Predominantly thin (35-100 µm)</td>
<td>Predominantly thin (35-100 µm)</td>
</tr>
<tr>
<td>Palaeoenvironment</td>
<td>High energy; shallow neritic (peritidal)</td>
<td>Moderate-high energy; neritic (photic zone)</td>
<td>Low-moderate energy; deep neritic (at or below wave base) to upper slope</td>
<td>Low-moderate energy; deep neritic (at or below wave base) to upper slope</td>
</tr>
</tbody>
</table>

**Table 2.** Collection data (cephala/cranidia and pygidia only); number of individuals of each taxon equates to the maximum number of cephal/cranidia or pygidia.

<table>
<thead>
<tr>
<th>Locality: D-RH</th>
<th>cephal/a/cranidia</th>
<th>pygidia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protemnites magnificans</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Pterocephalid? indet.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL = 14 individuals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Locality: D-UCM</th>
<th>cephal/a/cranidia</th>
<th>pygidia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protemnites magnificans</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Pseudagnostus idalis</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Tsinaniid 2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL = 16 individuals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Locality: D-GG</th>
<th>cephal/a/cranidia</th>
<th>pygidia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudagnostus idalis</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Inmitagnostus inexpectans</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Peratagnostus aff. invalidus</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Corynecochus plumula</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Eugonocare tessellatum</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Meteoraspis etheridgei</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mindyrcusta oepiki sp. nov.</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>TOTAL = 39 individuals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Locality: D-BSW</th>
<th>cephal/a/cranidia</th>
<th>pygidia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idolagnostus ?agrestis</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ammagnostus sp.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Inmitagnostus inexpectans</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tomagnosta sp.</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Corynecochus plumula</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Eugonocare tessellatum</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Rhyssometopus thieiei</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Mindyrcusta oepiki sp. nov.</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Tsinaniid 1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL = 25 individuals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

specimens of *E. tessellatum* from D-BSW and D-GG1 being limited and fragmentary, they can be confidently assigned to this species.

**TRILOBITE ASSEMBLAGES AND RELATED PALAEOENVIRONMENTS**

There is limited knowledge of Cambrian trilobite biofacies in Australia (Jago 1973, 1990a, b; Shergold 1980, 1988). The vast majority of information on Cambrian trilobite biofacies has come from quantitative studies on North American faunas (see Westrop & Cuggy 1999; Westrop & Adrain 2001; and references therein). Although only a limited number of specimens are available from the collections of each Dolodrock locality (see Table 2), the relative abundance of species at each locality was determined in order to detect the presence of distinct assemblages. Sedimentological data on the Dolodrock River limestones are also presented in Table 1.

Two distinct trilobite assemblages are evident in the Dolodrock River limestones: (1) the *Protemnites* Assemblage (Fig. 3), containing *Protemnites magnificans*, *Pterocephalid?* gen. et sp. indet., *Tsinaniid* gen. et sp. indet. 2 and *Pseudagnostus idalis*, and occurring at localities D-RH and D-UCM; and (2) the *Mindyrcusta* Assemblage (Fig. 4), containing *Mindyrcusta oepiki*, *Eugonocare tessellatum*, *Rhyssometopus thieiei*, *Meteoraspis etheridgei*, *Corynecochus plumula*, *Tsinaniid* gen. et sp. indet. 1, *Idolagnostus ?agrestis*, *Pseudagnostus idalis*, *Inmitagnostus inexpectans*, *Peratagnostus aff. invalidus*, *Tomagnosta* sp., and *Ammagnostus* sp., and occurring at localities D-GG and D-BSW. The *Protemnites* Assemblage is interpreted as representing an autochthonous assemblage inhabiting a moderate to high energy, inner shelf (peritidal) environment (Fig. 5). The *Mindyrcusta* Assemblage represents a paraautochthonous assemblage inhabiting a low to moderate energy, open ocean-facing, outer shelf to upper slope environment (Fig. 5).
magnificans, representing 79% and 88% of the trilobite fauna respectively (Fig. 3). There is limited information on the facies distribution of Proetmites, although its occurrence in various successions in Australia suggest that Proetmites is restricted to neritic environments (Henderson 1976a; Shergold 1982; Powell et al. 1982). Sedimentological data from D-RH and D-UCM supports this view (Table 1).

Taphonomic data from the Dolodrook River limestones are limited, but available evidence suggests that sclerites from D-RH and D-UCM have undergone minimal (if any) transportation, thus representing an autochthonous assemblage. Sclerites are disarticulated (although one partially articulated thorax has been found; Fig. 10M-N), and larger specimens show signs of breakage. Thin sections show that cuticles display a predominantly convex-up orientation, suggestive of being hydrodynamically stable in agitated waters (Speyer 1987). Moreover, associated librigenae and hypostomes are not uncommon, especially those of Proetmites. Unequal numbers of these differently shaped sclerites (cranidia, pygidia, librigenae and hypostomes) indicates that some shape-sorting has taken place (Speyer 1987). However, in the case of Proetmites, specimens of cranidia and pygidia from D-RH and D-UCM show a similar ratio (Table 2), suggesting that hydrodynamic conditions do not seem to have influenced the sorting pattern of these various sclerites. Westrop (1992) has observed a similar example of shape-sorting in sclerites of Arapahoa from the Upper Cambrian (Marjuman) Big Cove Member of the Petit Jardin Formation (Port au Port Group), western Newfoundland. This taphonomic information contained within the grainstones and packstones (with the presence of ooids and peloids) of D-RH and D-UCM suggests that the
Protenmites Assemblage represents an in situ assemblage inhabiting a moderate to high energy, shallow marine (inner shelf) environment.

Cuticle thicknesses observed in thin sections from D-RH and D-UCM (Table 1) are certainly within the range typical of inshore shelf environments (sensu Fortey & Wilmot 1991). Trilobites from D-RH and D-UCM have predominantly thick cuticles (170-350 μm), most likely belonging to Protenmites based on relative abundances, although thin cuticles are also present. This conforms to the pattern observed by Fortey & Wilmot (1991) in that inshore facies contain the full spectrum of cuticle thicknesses. Pratt (1998) has also observed similar thicknesses (200-350 μm) within grainstones of the Upper Cambrian Rabbitkettle Formation, which is consistent with their derivation from a high energy, shallow-water environment.

Associated faunas from D-RH and D-UCM include articulate and lingulate brachiopods (Brock & Talent 1999; Engelbreten 2004; respectively), crinoids, sponge spicules and gastropods. Shergold & Webers (1992) recorded a similar fauna associated with Protenmites magnificans from the Minaret Formation at Springer Peak, Heritage Range, West Antarctica. Of particular interest is the occurrence of the articulate brachiopod Roanella playstropheoides (Chapman). Brock & Talent (1999, p. 110) consider this species to be an opportunistic one within a high energy, near-shore environment ‘based on its restricted facies distribution, overwhelming faunal dominance, high density clustering, limited lateral distribution, and restricted stratigraphic occurrence’. The shell structure and taphonomy of Roanella specimens is analogous to sclerites of Protenmites. Roanella possesses a thick pedicle valve (up to 2 mm thick), and shells display a high level of disarticulation (97%), abrasion and breakage. The occurrence of lingulate brachiopods from D-RH and D-UCM is also noteworthy – specimens are rare, commonly fragmented and of low diversity (Engelbreten 2004), suggestive of a high-energy environment.

Mindycrusta Assemblage

Trilobite assemblages from localities D-GG and D-BSW display a higher diversity than those from D-RH and D-UCM (i.e., the Protenmites Assemblage), especially agnostids. Mindycrusta oepiki sp. nov. represents the most dominant taxon at localities D-GG and D-BSW, comprising 28% and 45% of the trilobite fauna respectively (Fig. 4). Composition of the trilobite faunas at D-GG and D-BSW differ slightly, though the taxa Eugonocare tessellatum, Corynexochus plumula and Ininitagnostus inexpectans are represented at both localities. Agnostids are generally regarded as indicators of deep-water (ocean-facing) environments, favouring habitats at the oceanic/neritic boundary (Lochman-Balk & Wilson 1958; Robison 1976; Pratt 1992). Pegel (2000) has noted that the agnostids Tomagnostella, Ininitagnostus and Ammagnostus are characteristic of the upper slope on the Siberian Platform, and that Peragnostus inhabited the lower slope. Many of the species from D-GG and D-BSW, such as Ininitagnostus inexpectans, Pseudagnostus idalis, Idolagnostus ?agrestis and Peragnostus aff. invalidus, also occur in the mixed platform and slope faunas of the Jiangnan Slope Belt, northwestern Hunan, China (Peng 1987, 1992; Peng & Robison 2000).

The polymerids Eugonocare, Corynexochus and Rhysometopus also seem to be characteristic of deep-water environments. Pratt (1992) recognised the ‘Eugonocare-Aphelaspis Biofacies’ (also containing Ininitagnostus and Pseudagnostus) in the Rabbitkettle Formation, southern Mackenzie Mountains, Canada, as representing a slope assemblage. Similar faunas to Pratt’s (1992) ‘Eugonocare-Aphelaspis
Biofacies’ occur in the deep-water Conasauga Formation at Cedar Bluff, Alabama, and in the Dunderberg Formation at McGill, Nevada (Palmer 1962). Pegel (2000) has reported the occurrence of *Eugonocare* and *Corynexochus* from lower slope biofacies on the Siberian Platform. Jago (1990b) has documented *Eugonocare*, *Corynexochus* and *Pseudagnostus idalis* from Idamean (early Late Cambrian) deep-water faunal assemblages in Tasmania. Peng (1992) has also recorded *Eugonocare* and *Corynexochus* from slope deposits of the Jiangnan Slope Belt, northwestern Hunan, China. The polynoid faunas from the Middle-Upper Cambrian Huaqiao Formation of the Jiangnan Slope Belt are yet to be formally described, but Peng et al. (2001a, b) have reported the occurrence of *Rhyssometopus* and *Corynexochus* from this unit.

Taphonomy of sclerites from D-GG and D-BSW suggest a minor amount of reworking. Westrop (1995) noted that reworked sclerites have either been moved from shelf to slope settings by turbidity or debris flows or reworked by major storms resulting in little or no transportation. Sclerites from D-GG and D-BSW are disarticulated and mostly unbroken, and thin sections show that they are randomly orientated, i.e., showing both convex-up and convex-down positions as well as being almost perpendicular to bedding (with some showing imbrication). This is suggestive of the sclerites being reworked by waning flow deposits, such as turbidity or debris flows. This is supported by sedimentological evidence, with sediments from D-GG and D-BSW showing graded beds, in addition to minor amounts of algal pellets and echiinoderm and mollusc fragments that were likely swept from shallower water. Speyer (1987) has suggested that bioturbation will also result in random orientations of sclerites, although, there is no evidence of bioturbation in sediments from D-GG and D-BSW.

Trilobites from D-GG and D-BSW have predominantly thin cuticles (35-100μm). This complies with the model of Fortey & Wilmot (1991) wherein offshore facies contain only thin cuticle while thicker cuticles, typical of inshore facies, are completely absent.

There is a lower diversity of associated faunas from localities D-GG and D-BSW (Table 1). As mentioned above, it is likely that echinoderm and mollusc debris is allochthonous, having been swept from shallower water, though the diverse and abundant lingulate brachiopod fauna represents an *in situ* deep-water assemblage (Engelbretsen 2004). Bassett et al. (1999) have interpreted the cosmopolitan micromorphic linguliformean genera such as *Anabolotrema*, *Dactylotrema*, *Limmarssonia*, *Neotrema*, *Picnotreta*, *Stilpnotreta* and *Treptotretra*, which all occur at D-GG and D-BSW, as representing typical inhabitants of slope-basin and outer shelf biofacies.

**SYSTEMATIC PALAEOONTOLOGY**

The terminology employed follows Shergold et al. (1990) and Whittington & Kelly (1997). Specimens are housed in the Commonwealth Palaeontological Collection (prefix CPC) at Geoscience Australia, Canberra.

**Agnostoids** (J.R. Laurie)

Order AGNOSTIDA Salter, 1864
Superfamily AGNOSTOIDEA M'Coy, 1849
Family AGNOSTIDAE M'Coy, 1849
Subfamily AGNOSTINAE M'Coy, 1849

**Innitagnostus** Œpik, 1967

**Type species.** *Innitagnostus innitens* Œpik, 1967

**Remarks.** In some recent works, *Innitagnostus* Œpik, 1967, has either been synonymised with *Micagnostus* or *Agnostus* (Robison 1994, p. 30; Peng & Robison 2000, p. 11), or has been considered a valid genus (Shergold et al. 1990, p. 33; Shergold & Laurie 1997, p. 341). Robison (1994) assigned the type species of *Innitagnostus* (*I. innitens* Œpik, 1967) to *Micagnostus* and considered it to be transitional between *Agnostus* and *Micagnostus*. In synonymising *Innitagnostus*, Robison (1994) apparently considered only the two features listed by Œpik (1967, p. 98) in his differential diagnosis as separating the genus from *Agnostus* and others. *Innitagnostus* was stated by Œpik to have ‘lateral notching’ (by F1 and F2) of the glabella and ‘angulate recesses’ at the base of the glabella which are occupied by the basal lobes. Robison (1994) maintained that the illustrations of *A. pisiformis*, the type species of *Agnostus*, given by Henningsmoen (1958, pl. 5, figs 1-12), showed ‘that some specimens have a glabella notched to fit the basal lobes’ while some also have weakly developed F1 and F2 furrows “giving a ‘laterally notched’ aspect to the glabella”, thus calling into question Œpik’s separation of *Innitagnostus* from other genera. Superficially, this sounds like a reasonable argument. However, if one has a closer look at the work of Henningsmoen (1958), who illustrates 5 holaspid cephalas of *A. pisiformis* (his figs 1, 3-6), it is clear that only one has a clearly notched glabella, while none of them have recessed basal lobes. Thus, Robison’s assertions seem lacking in a strong foundation. One should also realise that there are features other than those
Fig. 6. A, *Idolagnostus ?agrestis* Ōpik, 1967; cephalon, normal view, from D-BSW1, CPC37273; x15. E, *Ammagnostus* sp.; partial pygidium probably belonging to this species, normal view, from D-BSW1, CPC37256; x15. B-D, F-N, *Pseudagnostus idalis* Ōpik, 1967; B, F, cephalon, anterolateral oblique and normal views respectively, from D-GG3, CPC37264; C, D, cephalon, normal and anterolateral oblique views respectively, from D-GG2, CPC37257; G, H, cephalon, lateral and normal views respectively, from D-GG3, CPC37263; I, J, partial pygidium, normal and lateral views respectively, from D-GG3, CPC37266; K, partial cephalon, normal view, from D-GG2, CPC37267; L, partial cephalon, normal view, from D-GG3, CPC37270; M, pygidium, normal view, from D-UCM1, CPC37271; N, partial pygidium, normal view, from D-GG3, CPC37269; all x10. O-Q, *Innagnostus inexpectans* (Kobayashi, 1938); O, cephalon, normal view, from D-BSW1, CPC37254; P-Q, partial cephalon, anterolateral oblique and normal views respectively, from D-GG1, CPC37255; all x10. R-S, *Peragnostus aff. invalidus* (Lu & Lin, 1989), distorted pygidium, lateral and normal views respectively, from D-GG1, CPC37275. T-U, *Tomagnostella* sp., cephalon, anterolateral oblique and normal view respectively, from D-BSW1, CPC37274; all x10.
listed by Örik, which can be used to distinguish these two genera.

In the author’s opinion, Agnostus can be easily distinguished from Ininitagnostus. Agnostus has an ogival or rounded anterior glabellar lobe; lacks or has weakly developed glabellar F1 and F2 furrows, has basal lobes which are not recessed and lacks or has weakly developed pygidial F1 and F2 furrows. Ininitagnostus, on the other hand, has a broad, trapeziform anterior glabellar lobe, strongly developed glabellar F1 and F2 furrows, basal lobes recessed behind F1 and strongly developed pygidial F1 and F2 furrows.

It is also worth noting that, unlike species, genera are not biological entities. They are simply a means of communication and there is no standard methodology for setting their boundaries. Therefore, the validity of genera is simply a matter of opinion and any meaningful discussion of what constitutes a genus must wait until there is some systematic way of determining their boundaries.

**Ininitagnostus inexpectans** (Kobayashi, 1938) (Fig. 6O-Q).

1967 *Ininitagnostus inexpectans* (Kobayashi); Örik, 1967, p. 101, pl. 63, fig. 2.
1982 *Ininitagnostus inexpectans* (Kobayashi); Shergold, p. 20, pl. 5, figs 1-6.
2000 *Agnostus inexpectans* Kobayashi; Peng & Robison, p. 12, fig. 7.

**Material.** 2 cranidia, CPC37254-37255.

**Localities.** D-GG1 and D-BSW1.

**Description.** Cephalon rounded, moderately convex, clearly furrowed, smooth (Fig. 6P-Q) or weakly scrobiculate (Fig. 6O). Border narrow, roll-like, slightly wider anteriorly; border furrow narrow. Preglabellar median furrow narrow, fairly weak, becoming shallower anteriorly. Glabella clearly outlined by narrow axial furrow, occupying 67% (n=2) of cephalic length. Anterior glabellar lobe occupying 35% (n=2) of glabellar length (sag.), subquadrate, indented anteriorly by short sulcus, separated from posteroglabella by shallow, narrow, nearly straight F3 furrow. Posteroglabella moderately convex (tr.), rising from anterior margin to reach its maximum height about level with the F1 furrows. Glabellar node obscure. F2 furrows fairly well defined, but of varying width. Posteroglabella narrows abruptly level with F1 furrows, such that basal lobes are inset into rear of glabella.

**Remarks.** These two cephala are assigned to *I. inexpectans* with a great degree of confidence because they possess the relatively long anterior glabellar lobe, and the relatively well developed preglabellar median furrow.

Subfamily AMMAGNOSTINAE Örik, 1967

*Ammagnostus* Örik, 1967

**Type species.** *Ammagnostus psammium* Örik, 1967

*Ammagnostus sp.* (Fig. 6E)

**Material.** A single, poorly preserved, partial pygidium, CPC37256.

**Localities.** D-BSW1.

**Description.** Short, broad, rounded pygidium with wide border and fairly wide border furrow. Posterolateral spines short, advanced, about level with midlength of posterior lobe of pygidial axis. Pygidial axis broad, strongly constricted across M2, with large, expanded, posterior axial lobe which extends to the border furrow. F1 and F2 apparently effaced. Other details obscure.

**Remarks.** This specimen has the broad border, wide border furrow and long, wide axis characteristic of species of *Ammagnostus*. However, the species to which this specimen belongs cannot be determined.

Subfamily PSEUDAGNOSTINAE Whitehouse, 1936

**Pseudagnostus** Jaekel, 1909

**Type species.** *Agnostus cyclopyge* Tullberg, 1880

**Remarks.** In a recent work, Peng & Robison (2000, p. 16) synonymised a host of pseudagnostid species including such different species as *P. vastulus* Whitehouse, 1936, *P. idalis* Örik, 1967 and *P. ampullatus* Örik, 1967. It is difficult to justify every one of these synonymies, given that characters (e.g. glabellar node position) which have proven to be useful in delimiting pseudagnostid species in the review by Shergold (1977), as well as species in other groups ofagnostids, are seemingly dismissed out of hand. It is far beyond the scope of this paper to attempt to revise the Pseudagnostidae, so for the time being, the usage of Shergold (1977, 1982) is followed.

**Pseudagnostus idalis** Örik, 1967 (Fig. 6B-D, F-N)

1967 *Pseudagnostus idalis*; Örik, p. 153, pl. 62,
figs 8-9, pl. 63, figs 1, 3.
1982 Pseudagnostus (Pseudagnostus)idalis Opik;
Shergold, p. 26, pl. 2, figs 1-15, pl. 3 figs 1-8.

Material. 13 cephalas, 3 pygidia, CPC37257-37272.

Localities. D-GG2, D-GG3 and D-UCM1.

Description. Cephalon rounded, moderately convex, clearly furrowed, smooth or finely granulose. Border narrow, roll-like, narrowing slightly from anterior to lateral margin, becoming very narrow near posterolateral extremity. Border furrow deliquiate, as wide as, or wider than border. Preglabellar median furrow always present, but broad and poorly defined. Glabella clearly outlined by broad axial furrow, about 68% (n=4) as long as cephalon. Anterior glabellar lobe about 26% (n=5) glabellar length (sag.), transverse, semiovate to semicircular. F3 furrow variable, from nearly straight (Fig. 6K) to strongly bent rearwards (Fig. 6C). Posteroglabella moderately convex, slightly constricted across F2 and with variably expanded posterolateral lobes. Glabellar node elongate, located level with posterior margins of posterolateral lobes. F1 furrows absent. Basal lobes large, triangular, separated from remainder of glabella by strong basal furrows. Posterior termination of glabella obtusely angulate.

Pygidium rounded, moderately convex, clearly furrowed except for posteroaxis, which is almost completely effaced. Border narrow, roll-like, of fairly even width. Border furrow strongly deliquiate, at least as wide as border, of greatest width posterolaterally where it may be more than twice as wide as border. Axial furrow tapers slightly posteriorly to intersection with F2, where it bends abruptly away from the midline and quickly becomes effaced. F1 furrow completely effaced or weakly developed laterally. F2 furrow well developed, bent rearwards around large, elongate, pygidial node.

Remarks. These specimens are assigned to P. idalis Opik, 1967 insofar as the cephalas are essentially identical to those assigned to this species by Opik (1967) and Shergold (1982). However, unlike the pygidia illustrated herein, those assigned to P. idalis by Opik (1967) have the axial furrow clearly visible almost all the way to the border furrow. This is in part due to Opik’s specimens being exfoliated. However, the specimens assigned to P. idalis and illustrated by Shergold (1982) show a greater variation in the degree of effacement of the axial furrow and the specimens illustrated herein fall within that range of variation.

Idolagnostus Opik, 1967

Type species. Idolagnostus agrestis Opik, 1967

Idolagnostus ?agrestis Opik, 1967 (Fig. 6A)

?1967 Idolagnostus agrestis; Opik, p. 104, pl. 59, figs 9–10, pl. 60, figs 1–2; pl. 3, fig. 10.

Material. One poorly preserved cephalon, CPC37273.

Locality. D-BSW1.

Description. Cephalon, small, rounded-quadrate, with strongest curvature of margin anterolaterally. Preglabellar median furrow well developed. Anterior lobe of glabella short, broad, subtriangular, posteriorly rounded by shallow, narrow F3 which has a slight posterior bend across its middle third. F2 furrow very well defined, straight. Basal lobes small, triangular.

Remarks. Opik (1967) erected two species of this genus, the type species, I. agrestis, and I. dryas. Opik (1967, p. 106) separated I. agrestis from I. dryas by its more rounded cephalon, its posterior glabellar lobe being wider than the middle lobe, its wider, deeper furrows and its larger cephalic spines. The difference in the cephalic furrows can be attributed to difference in styles of preservation. This can be seen by comparing the three cephalas of I. dryas illustrated by Opik (1967, pl. 60, figs 3–5). His figures 3 and 4 have narrower furrows than those in figure 5. The furrows in the latter specimen are more like those in Opik’s specimens of I. agrestis (pl. 60, figs 1–2). This is not surprising because all three specimens are from the same locality (D29). The difference in size of the cephalic spines is barely discernible, so using this to separate these two species seems to be an overstatement of its utility. Also the variation in the roundness of the glabella seems relatively slight. Opik’s figure 4 (I. dryas) is very quadrate, while the other two assigned to that species (figs 3, 5) are similar to the larger of the two I. agrestis specimens (fig. 1). The holotype of I. agrestis is the most rounded of the five cephalas. This also seems to be a dubious criterion for distinguishing the two species. Opik also states that I. agrestis has its posterior glabellar lobe wider than the middle lobe, while the reverse is true in I. dryas. Again, this seems to be due to the preservation, with Opik’s figures 3 and 4 appearing to have a narrower posterior lobe, while the specimens in figures 1, 2 and 5 all seem to have a broader
posterior lobe and are all from the same locality. While it is possible that the specimen illustrated by Öpik in his figure 5 may be simply reassigned to *I. agrestis*, leaving his figures 3 and 4 with *I. dryas*, it seems more likely that all belong to one species. All of these cephalas are of similar proportions, being about 67% as long as wide, with the glabella occupying about 69% of the cephalic length, the anteroglabella comprising about 25% of the total glabellar length, and the glabella being about 49% as wide as long. Therefore, *I. agrestis* and *I. dryas* are considered synonymous here. The specimen described above from the Dolodrock limestones clearly belongs to *Idolagnostus* because of the distinctive subdivision of the glabella. The rounded-quadrate shape of the cephalon is similar to the shape of the cephalon of *I. agrestis* (= *I. dryas* Öpik, 1967). However, the glabella is considerably broader than that of *I. agrestis*, being 53% as wide as long, compared to 46% in Öpik’s species. This could be due to the distortion of the Dolodrock specimen, but one specimen is not sufficient to draw such conclusions, so the assignment to *I. agrestis* is questioned.

Family HYPAGNOSTIDAE Ivshin, 1953

Remarks. This family was considered a junior synonym of Spinagnostididae Howell, 1935 and Cyclopagnostididae Howell, 1937 by Shergold et al. (1990) and Shergold & Laurie (1997). However, this family is resurrected in the light of Robison’s (1994) reassessment of Howell’s original material of the type species of Spinagnostus (S. franklinensis) and Cyclopagnostus (C. hesperius), both of which he considered to be unrecognisable. Hence Spinagnostus and Cyclopagnostus are unrecognisable taxa, as are the family names based on these genera; the Spinagnostididae and Cyclopagnostididae, respectively. Thus, by virtue of their being unrecognisable taxa, the names Spinagnostusidae and Cyclopagnostidae cannot be used. As a consequence, the next oldest name for the family containing Hypagnostus and similar genera becomes available for use. That name is Hypagnostus Ivshin, 1953.

Robison (1988), Pratt (1992) and Peng & Robison (2000) all assign Tomagnostella to the Ptychagnostididae because it “differs from Hypagnostus in pygidial characters, which are ptychagnostid, commonly with ring furrows, rather than peronopsid, commonly without ring furrows” (Peng & Robison 2000, p. 84). While it is true that most ptychagnostids have pygidial F1 and F2 furrows, but in some genera they are well developed (e.g. Diplorrhina). Furthermore, the style of glabellar effacement that is seen in Tomagnostella (i.e. complete effacement of the anterior glabellar lobe, with little or no effacement of the posterior lobe) is unknown among the Ptychagnostididae except for the problematic *Myrmecomimus? arctus* (Pokrovskaya & Egorova) (Egorova et al. 1976). This kind of effacement is essentially identical to that in Hypagnostus. Therefore, although one could easily argue either way, Tomagnostella is for the time being still assigned to the Hypagnostidae.

**Tomagnostella** Kobayashi, 1939

*Type species. Agnostus excultus* Angelin, 1851

**Tomagnostella sp.** (Fig. 6T-U)

**Material.** One cephalon, CPC37274.

**Locality.** D-BSW1.

**Description.** Cephalon slightly elongate, strongly convex, with narrow, roll-like border and very narrow border furrow. Posteroglabella subovate, moderately convex, widest a short distance anterior to midlength, anterior margin obtusely subangulate, posterior margin evenly rounded. Basal lobes fairly large, triangular, laterally bounded by concave section of axial furrow.

**Remarks.** This specimen is similar in many respects to Tomagnostus sulcifera (Wallerius, 1895) and Tomagnostus excultus (Angelin, 1851), but its lack of a pygidium precludes specific assignment.

**Peragnostus** Öpik, 1967


**Peragnostus aff. invalidus** (Lu & Lin, 1989) (Fig. 6R-S)

aff. 1989 Tomagnostella? invalida; Lu & Lin, p. 110, pl. 12, figs 9-12.

**Material.** One partial pygidium, CPC37275.

**Locality.** D-GG1.

**Description.** Pygidium elongate, strongly convex, with narrow, slightly flattened border and very narrow border furrow. Pygidial axis clearly defined,
long, narrow, constricted across M2, not extending to border furrow. M1 fairly wide, with maximum length about twice sagittal length. F1 weakly defined, with lateral portions straight, converging forward at an angle of about 120 degrees, median portion evenly curved, so that furrow appears strongly bent forward. F2 furrow very weakly developed, bent slightly rearward around moderately large pygidial node. Posteroaxis long, lanceolate, with narrowly rounded termination.

Remarks. This unusual pygidium is similar to the best preserved of the pyidia assigned to Tomagnostella? invalida by Lu & Lin (1989, pl. 12, fig. 11) and to the pygidia assigned to Peragnostus cf. invalidus by Peng (1992, p. 23) except that the pygidial shoulders are more angulate and the pygidial axis is slightly broader. Because it is difficult to make conclusions based on this single specimen and because the material of T? invalida Lu & Lin is mostly poorly preserved, the Dolodrook specimen is left under open nomenclature. Despite coming from separate localities, it is possible that this specimen belongs to the same species as that assigned to Tomagnostella sp. above. However, the axial furrow is weakly impressed, and the F1 and F2 furrows are almost effaced, states not known in species of Tomagnostella as currently understood, so this specimen is assigned to Peragnostus.

Polymerid trilobites (J.R. Paterson)

Order CORYNEXOCHIDA Kobayashi, 1935
Family CORYNEXOCHIDAE Angelin, 1854

Corynexochus Angelin, 1854

*Type species.* Corynexochus spinulosus Angelin (1854, p. 59, pl. 33, figs 9, 9a, non fig. 11).

*Corynexochus plumula* Whitehouse, 1939 (Fig. 7A-C)


*Material.* 3 cranidia, CPC37276-37278.

*Localities.* D-GG2 and D-BSW1.
Remarks. *Corynexochus plumula* has been adequately described by Whitehouse (1939, p. 234) and Opik (1967, p. 178), and has been well documented from several other palaeogeographic provinces including China (Duan *et al.* 1999, see synonymy therein), Kazakhstan and Siberia (Lisogor *et al.* 1988), and North America (Palmer 1968; Pratt 1992). *C. plumula* represents the only known species of *Corynexochus* from Australia.

As noted by Peng (1992, p. 34), the majority of species of *Corynexochus* are Middle Cambrian in age. Other Late Cambrian species occur only in China (Zhu *et al.* 1979; Zhou *et al.* 1982; Peng 1992; Duan *et al.* 1999), but unfortunately the majority are known from a limited number and often poorly preserved specimens. The one exception is *C. chinensis*, originally described by Lin & Zhang (in Zhu *et al.* 1979) from North China, and
later documented by Peng (1992) from the Cili-Taoyuan area of northwestern Hunan. *C. chinensis* is distinguished from *C. plumula* in having a narrower (tr.) glabella, longer palpebral lobes, narrower fixigenae, and a shorter (sag.) pygidium.

Order ASAPHIDA Salter, 1864
Suborder ASAPHINA Salter, 1864
Superfamily RHYSSEMETOPOIDEA Ōpik, 1967
Family RHYSSEMETOPIDAE Ōpik, 1967

**Rhyssometopus** Ōpik, 1967

*Type species*. *Rhyssometopus (Rhyssometopus) rhyssometopus* Ōpik (1967, p. 274, pl. 25, figs 1-4; pl. 33, fig. 4; pl. 46, fig. 3).

**Rhyssometopus thielei** (Chapman, 1911) (Fig. 8A-K)

1911 *Ptychoparia thielei*; Chapman, p. 316, pl. 58, figs 3, 5, 7, non figs 2, 10.
1911 *Ptychoparia minima*; Chapman, p. 318, pl. 58, fig. 1, non fig. 6.

*Diagnosis*. A species of *Rhyssometopus* with four distinct lateral glabellar furrows, S1 and S2 are subparallel and directed forwards abaxially, S3 is transverse, S4 is directed backwards abaxially; L1 inflated transversely; axial furrows are deep and sinuous; anterior cranial margin is slightly convex anteriorly, short (sag.) frontal area; anterior cranial border and preglabellar field undifferentiated; paradoublural lines almost straight and diverge anteriorly at 125°; narrow (tr.) palpebral lobes; wide palpebral area, width (tr.) at midlength of palpebral lobe is approximately 45% adjacent width (tr.) of glabella. Width (tr.) of pygidial axis is approximately 30% pygidial width; axis with three well developed axial rings and a terminal piece; three moderately developed pleural furrows separating three pleural ribs of low relief with faint interpleural furrows.

*Material*. Neotype: partial cranium, CPC37283 (Fig. 8E-G). Neoparatypes: 3 cranidia, CPC37284-37286 (Fig. 8A-D); 1 librigena, CPC37287 (Fig. 8H); 6 pygidia, CPC37288-37293 (2 illustrated, Fig. 8I-K).


*Remarks*. The cranidia from the Dolodrook River limestones illustrated by Chapman (1911) and referred to as *Ptychoparia minima* (Chapman 1911, pl. 58, fig. 1) and *Ptychoparia thielei* (Chapman 1911, pl. 58, figs 3, 7) closely resemble cranidia collected from locality D-BSW. Although incomplete, cranidia illustrated by Chapman (1911) and those from D-BSW have a subquadrate glabella, long arcuate palpebral lobes, the anterior tips of which contact the glabella, deep palpebral furrows and granulose ornament, all characteristic features of *Rhyssometopus*. Unfortunately, the present location of the type material of *P. minima* and *P. thielei* is unknown, presumed lost, as is the case with the remainder of Chapman’s (1911) trilobite type material from the Dolodrook River limestones (D. J. Holloway, pers. comm., 2003). Therefore, since new specimens from D-BSW represent topotype material, the partial cranium CPC37283 from D-BSW is designated as the neotype of *Rhyssometopus thielei* (Chapman).

*Rhyssometopus thielei* is easily distinguished from other species of the genus in that it possesses a wide (tr.) palpebral area and well marked glabellar furrows. The width (tr.) at the midlength of the palpebral lobe is approximately 45% of the adjacent width (tr.) of the glabella, whereas in other species the palpebral area width varies between 22% and 35% adjacent glabella width. *R. thielei* is most similar to *R. rugiceps* Ōpik (1967, pl. 25, figs 5-8) in that both species have a short (sag.) frontal area, slightly convex anterior cranial margin, three axial rings on the pygidium, and three moderately developed pleural furrows separating three pleural ribs of low relief. *R. rugiceps* is readily differentiated from *R. thielei* in having a defined anterior border furrow, almost transverse paradoublural lines, subparallel-sided glabella, and wide (tr.) palpebral lobes.

Order PTYCHOPARIIDA Swinnerton, 1915
Suborder PTYCHOPARIINA Swinnerton, 1915
Superfamily PTYCHOPARIOIDEA Swinnerton, 1915
Family PTEROCEPHALIIDAE Kobayashi, 1935
Subfamily APHELASPIDINAE Palmer, 1960

**Eugonocare** Whitehouse, 1939

*Type species*. *Eugonocare tessellatum* Whitehouse (1939, p. 226, pl. 23, figs 15, 17, non figs 16, 18; pl. 25, fig. 7b).

**Eugonocare tessellatum** Whitehouse, 1939 (Fig. 9A-L)

For synonymy, see Shergold (1982, p. 38).

*Material*. 12 cranidia, 3 librigena, 3 pygidia, CPC3794-37311.

*Localities*. D-GG1, D-GG2, D-GG3 and D-BSW1.
Fig. 9. *Eugonocare tessellatum* Whitehouse, 1939. A-D, partial cranium, from D-GG3, CPC37294; A, dorsal view, x2.5; B, anterior view, x2; C, lateral view, x2.5; D, oblique anterolateral view, x2.5; E, partial cranium, dorsal view, from D-GG3, CPC37298, x3; F, partial cranium, dorsal view, from D-GG3, CPC37295, x3; G, partial librigena, dorsal view, from D-GG2, CPC37306, x3; H, partial librigena, dorsal view, from D-GG3, CPC37300, x3; I, partial librigena, dorsal view, from D-GG3, CPC37305, x3; J, partial pygidium, dorsal view, from D-GG3, CPC37299, x4; K, partial pygidium, dorsal view, from D-GG2, CPC37301, x3.5; L, partial pygidium, dorsal view, from D-GG3, CPC37304, x4.

**Remarks.** This species has been well documented by Whitehouse (1939), Henderson (1976a) and Shergold (1982). As noted by Henderson (1976a) and Shergold (1982), Australian species of *Eugonocare* have almost indistinguishable crania and are diagnosed essentially on pygidial characteristics. Pygidia of *Eugonocare* can usually be differentiated by length (sag.)/width (tr.) ratios (see Henderson 1976a, text-fig. 3). Further defining pygidial characters include: (1) number of axial rings – *E. tessellatum* and *E. quadrata* have five axial rings, whereas *E. whitehousei* has six; and (2) outline – both *E. tessellatum* and *E. whitehousei* are semicircular in outline, (though the latter has an indentation in the medial region of the posterior margin), and *E. quadrata* is subtriangular in outline. Pygidia from the Dolodrock closely resemble those of *E. tessellatum* illustrated by Henderson (1976a, pl. 50, figs 2-4) and Shergold (1982, pl. 10, figs 5, 7, 8) in being semicircular in outline, having a sagittal length approximately 50% width (tr.), and
Fig. 10. *Protemnites magnificans* Shergold & Webers, 1992. A, cranidium, dorsal view, from D-RH5, CPC37312, x2; B-D, cranidium, from D-RH5, CPC37316; B, dorsal view, x2; C, lateral view, x2.5; D, anterior view, x2.5; E, cranidium, from D-RH5, CPC37315; E, dorsal view, x2.5; F, lateral view, x3; G, H, cranidium, from D-RH5, CPC37317; G, lateral view, x2.5; H, dorsal view, x2.5; I, J, hypostome, (continued opposite)
possessing five axial rings.

**Protemnites** Whitehouse, 1939

1939 *Protemnites*; Whitehouse, p. 209.
1976a *Prismenaspis*; Henderson, p. 348.

*Type species.* *Protemnites elegans* Whitehouse (1939, p. 210, pl. 22, figs 12a-b, *non* fig. 13) [see also Shergold (1982, pl. 9, fig. 1) for refuged holotype].

Other species. *Protemnites propinquum* (Whitehouse, 1939); *P. brownensis* (Henderson, 1976a); *P. trisulcatus* (Ergaliev, 1980); *P. magnus* (Ergaliev, 1980); *P. burkensis* Shergold, 1982; *P. magnificans* Shergold & Webers, 1992. [*P. waergangensis* described by Peng (1992) is not considered herein to represent a species of *Protemnites*].

Remarks. In Shergold’s (1982) review of *Protemnites*, he advocated that *Prismenaspis* is likely to be a junior subjective synonym of the former genus. Henderson (1976a, p. 350) distinguished *Prismenaspis* from *Protemnites* by its “possessing an additional [fourth] pair of lateral glabellar furrows and by the weak impression of all four pairs of furrows”. However, as noted by Shergold (1982), cranidia of *Prismenaspis* illustrated by Henderson (1976a, pl. 50, figs 6, 7, 10, 17, 18) do not display a fourth pair of lateral glabellar furrows. In addition, cranidia of *Protemnites* also show weakly impressed glabellar furrows and therefore this cannot be considered a valid distinguishing feature. Henderson (1976a, p. 350) further distinguished *Prismenaspis* “by the obliquity of its eye ridges and by the inflated pleural regions of its pygidium”. The course of the eye ridges on cranidia of *Prismenaspis* illustrated by Henderson (1976a) do not appear to differ from the holotype cranidium of *Protemnites elegans*. Moreover, comparisons between the pygidia of *Prismenaspis* and *Protemnites elegans* are impossible as they are unknown in the latter – the pygidium of *Protemnites elegans* illustrated by Whitehouse (1939, pl. 22, fig. 13) represents a pagodiid. Therefore, *Prismenaspis* is considered herein to be a junior subjective synonym of *Protemnites*.

In regard to higher level classification, *Protemnites* appears to be closely allied with genera such as *Onchopelits* Rasetti, *Olenella* Ivshin and *Aphelaspis* Resser, suggesting placement in the subfamily Aphelaspidinae. Shergold & Webers (1992, p. 139) noted that the cranidia of *Protemnites*, *Onchopelits* and *Olenella* intergrade morphologically, resembling each other in the “structure of the preglabellar area, in glabellar shape and degree of effacement of the glabellar furrows, and in palpebral morphology”. Further evidence to support the close affinity of these genera is apparent in their pygidial morphology. All of the above mentioned genera possess a small ellipsoidal pygidium with a wide (tr.) axis containing three or four axial rings, commonly with weakly developed pleural ribs, and a border that is widest laterally and tapers adaxially. The hyposome of *Protemnites magnificans* illustrated herein (Figs 101-J, 11E-F) is typically Libristomate (*sensu* Fortey 1990) and closely resembles that of *Olenella* cf. *O. africana* illustrated by Shergold *et al.* (2000, pl. 2, fig. 11), *Onchopelits spectabilis* illustrated by Rasetti (1944, pl. 39, fig. 4), *Aphelaspis brachyphasis* illustrated by Palmer (1962, pl. 4, figs 18, 19), and *Aphelaspis walcottii* illustrated by Palmer (1954, pl. 84, fig. 2).

The problem of placing the Aphelaspidinae in either Pterocephalidae or Elviniiidae has been discussed in detail by Shergold (in Shergold & Cooper 1985, p. 98), Pratt (1992, p. 52-53) and Shergold *et al.* (2000, p. 610). We follow the view of Shergold *et al.* (2000) in temporarily accommodating the Aphelaspidinae in the family Pterocephalidae, and that if the subfamilies Pterocephalinae and Housiiinae are classified within the Anomocaridae (Asaphida) based on the presence of a median suture, Aphelaspidinae should be elevated to familial status within the Ptychoparioida.

**Protemnites magnificans** Shergold & Webers, 1992 (Figs 10A-R, 11A-I)

1992 *Protemnites? magnificans*; Shergold & Webers, p. 139, pl. 6, figs 1-6.
1992 *Protemnites* sp. aff. *elegans* Whitehouse; Shergold & Webers, p. 139, pl. 6, figs 7-9, 10?, 11.

**Material.** 25 cranidia, 13 librigena, 5 hypostomes,
1 partial thorax, 8 pygidia, CPC37312-37363.

Localities. D-RH5 and D-UCM1.

Description. The cranium of *Protemnites magnificans* has been adequately described by Shergold & Webers (1992, p. 139). With the new collections from the Dolodrook, it is now possible to document and describe the librigena, hypostome, thorax and pygidium of this species.

Librigenal width (tr.) approximately 60% length excluding spine; lateral margin strongly curved; posterior border short (tr.); lateral and posterior margins drawn into short, posterolaterally directed spine at genal angle. Genal field broad (tr.) and convex (tr., sag.); surface covered with coarse, evenly spaced granules and genal caeca. Border flat to slightly convex (tr.), width (tr.) approximately 25% width of librigena; anterior end strongly tapered into short, pointed projection; faint transverse ridge and shallow transverse bisecting furrow continuing from anterior cranial border; surface covered with coarse, unevenly spaced granules. Lateral and posterior border furrows shallow, meeting at genal angle.

Hypostome is long (sag.) and narrow (tr.), strongly convex (sag., tr.). Anterior wings are short (tr.) with rounded ends. Lateral and posterior borders are narrow and convex. A faint middle furrow traverses the middle body and separates the long (sag.) anterior lobe from the short (sag.) posterior lobe, and is deepest at the poorly defined...
maculae. Lateral border furrows are well impressed and are deepest anterior of the maculae.

Thorax of at least six segments (no complete thorax available). Axis strongly convex (tr.), width (tr.) approximately 30% width of each segment. Sixth segment of illustrated specimen (Fig. 10M-N) exhibits well developed axial spine. Well impressed pleural furrows wide (exxsag.) to fulcrum, then become narrower before terminating abruptly at base of pleural spine. Anterior and posterior bands of pleura of subequal width (exxsag.). Articulating facet wide and flat. Pleural spine short and non-falcate.

The thoracic morphology of Proetennites magnificans is almost identical to that in other aphetaspines such as Notoaphelaspis (see Powell et al. 1982, figs 11.3, 11.4, 11.7a-b) and Aphelaspis (see Palmer 1962, pl. 4, figs 14, 25, 31; Palmer 1965, pl. 9, fig. 20; Iago 1987, pl. 25, figs 9-11, 14). However, one major difference is that Proetennites magnificans possesses non-falcate or 'thorn-like' pleural spines whereas other aphetaspines display falcate pleural spines, or in the case of Notoaphelaspis and Australian species of Aphelaspis, a total absence of pleural spines.

Pygidium is small, transversely ellipsoidal, sagittal length approximately 50% width (tr.). Axial furrows shallow. Axis convex (tr.), elevated above pleural field, gently tapering posteriorly, occupying approximately 85% of the sagittal length of the pygidium, with posterior end contacting the border furrow; contains four axial rings and a broadly rounded terminal piece; width (tr.) of anterior portion of axis is approximately 35% pygidal width. Long (sag.) articulating half ring, length (sag.) approximately 25% axial lobe length. Weakly developed pair of pleural ribs near anterior margin of pygidium, remainder of pleural fields effaced. Border furrow more of a change in slope than a distinct furrow; anterior border furrow moderately impressed. Border flat to slightly convex, widest laterally and tapers adaxially. Pygidial margin smooth.

Remarks. Cranidia from the Dolodrook show a striking resemblance to those illustrated by Shergold & Webers (1992, pl. 6, figs 1-6) as Proetennites? magnificans from the Heritage Range, Ellsworth Mountains (Antarctica), in possessing a strongly curved anterior margin, wide (sag.) anterior cranidial border displaying a faint transverse ridge and shallow transverse bisecting furrow, and an anterior border furrow that is medially shallow and anteriorly deflected across the sagittal line. Other cranidia illustrated by Shergold & Webers (1992, pl. 6, figs 7-11) as Proetennites sp. aff. P. elegans are very similar to those of P. magnificans, but were separated because they have ‘a transverse rather than elongate cranidium with proportionately shorter (sag.), anteriorly rounded glabella, preglabellary and anterior cranidial border. The glabellary furrows are faint but are still visible on the exoskeletal surface, and the ocular ridges are almost transverse’. However, most cranidia assigned to Proetennites? sp. aff. P. elegans do not possess all of these features. For example, the cranidia illustrated by Shergold & Webers (1992, pl. 6, figs 7, 8) are elongate and display similar proportions of the preglabellar field and anterior cranidial border to P. magnificans. Furthermore, these same cranidia show a faint transverse ridge and shallow transverse bisecting furrow on the anterior cranidial border, suggesting they belong to P. magnificans. The cranidium USNM334010 illustrated by Shergold & Webers (1992, pl. 6, fig. 10) does resemble the holotype of P. elegans, but it is interesting to note that both cranidia of the same size, which in turn are considerably smaller than specimens of P. magnificans from the Heritage Range and the Dolodrook. The holotype of P. elegans may prove to be a small holaspisid and thus become a senior subjective synonym of P. magnificans; however until additional collections of P. elegans from western Queensland are made this remains speculative.

Cranidia illustrated by Powell et al. (1982, fig. 10.9-10.12) and identified as Prismenaspis? sp. nov. from the Cupala Creek Formation resemble Proetennites magnificans, despite the considerable distortion of the specimens. Jell (in Powell et al. 1982, p. 145) noted that the anterior cranidial border “bears a low but distinct transverse ridge” and this can be clearly seen in one cranidium illustrated by Powell et al. (1982, fig. 10.11). Furthermore, specimens possess an anterior border furrow that is medially shallow and anteriorly deflected across the sagittal line. Therefore, cranidia referred to Prismenaspis? sp. nov. by Powell et al. (1982) are herein tentatively assigned to Proetennites magnificans.

Pterocephaliid? gen. et sp. indet. (Fig. 7D-E)

Material. 1 cranidium, 3 pygidia, CPC37279-37282.
Locality. D-RH5.

Remarks. This species is represented by only one fragmentary cranidium and three fragmentary pygidia. It is similar in many respects to Pterocephaliid gen. et sp. nov. 1 illustrated by Peng et al. (2001a, pl. 5, fig. 6, pl. 7, figs 10, 11, pl. 9, figs 5, 6) from the Huaqiao Formation, northwestern Hunan, China. The Dolodrook cranidium differs
in having a gently tapered glabella with a more rounded anterior margin, while the pygidia differ in having a wider (tr.) axis.

Family TRICREPICEPHALIDAE Palmer, 1954

**Meteoraspis** Resser, 1935

*Type species.* *Psychoparia metra* Walcott (1890, p. 273, pl. 21, fig. 7).

**Meteoraspis etheridgei** (Chapman, 1911) (Fig. 11J-K)

1911 *Crepicephalus etheridgei* sp. nov.; Chapman, p. 319, pl. 58, fig. 8.

**Material.** Neotype: partial pygidium, CPC37364 (Fig. 11K). Neoparatype: 1 partial cranidium, CPC37365 (Fig. 11J).

**Locality.** D-GG4.

**Remarks.** The partial pygidium from Garvey Gully (D-GG) illustrated herein (Fig. 11K) is very similar to that of the holotype pygidium of *Crepicephalus etheridgei* illustrated by Chapman (1911, pl. 58, fig. 8), also from the Doldrook River limestones. Unfortunately, the whereabouts of the holotype of *C. etheridgei* is unknown (D.J. Holloway, pers. comm., 2003). Therefore, since new specimens from D-GG represent toptotype material, the pygidium CPC37364 is designated as the neotype of *Meteoraspis etheridgei* (Chapman). This species is better placed in *Meteoraspis* based on the revised generic diagnosis given by Palmer (1954, p. 753), in addition to the cranidium displaying a bluntly pointed glabella and very short (sag.) preglabellar field, also characteristic features of the genus.

Of the known species of *Meteoraspis* (listed by Wang et al. 1989, p. 112-113), *M. etheridgei* is closely related to the Australian species *M. bidens* Öpik, 1967 from the Mindyallian *Glyptagnostus stolidotus* Zone of western Queensland. *M. etheridgei* differs from *M. bidens* in having a considerably narrower pygidial border and narrow-based posterolateral spines. Although not all of the axial rings are preserved on the neotype pygidium, the illustrated pygidium in Chapman (1911) suggests the presence of four well developed axial rings and a terminal piece, whereas *M. bidens* has three distinct axial rings, with a fourth poorly defined (possibly fused to the terminal piece).

Family ASAPHISCIDAE Raymon, 1924

**Mindycrusta** Öpik, 1967

*Type species.* *Blountia* (*Mindycrusta*) mindycrusta Öpik (1967, p. 235, pl. 11, figs 4-10; pl. 12, figs 1-3).


**Remarks.** In Westrop’s (1992) taxonomic treatment of the Kingstoniidae, he stressed the importance of the very short (sag.) and depressed structure of the occipital ring among kingstoniid genera as being a defining synapomorphic character for the group. He noted that *Blountia* Walcott, previously assigned to the Asaphiscidae, has almost identical occipital ring morphology to that of the kingstoniid genera *Kingstonia* Walcott and *Bynunia* Walcott which is distinct from the longer, posteriorly bowed occipital ring of *Asaphicus* Meek. Westrop therefore tentatively assigned *Blountia* to the Kingstoniidae. He also noted that the pleurae of *Blountia* lack conspicuous pleural furrows, unlike those of *Asaphicus* that display distinct pleural furrows. Since species of *Mindycrusta* possess both a long (sag.) posteriorly bowed occipital ring (*Öpik* 1967, pl. 10, fig. 11; pl. 12, figs 2a, 4a, 5a; pl. 13, figs 1, 3a, 5a, 7, 8) and distinct thoracic pleural furrows (*Öpik* 1967, pl. 11, figs 4-6; pl. 12, fig. 3), *Mindycrusta* should be retained within the Asaphiscidae and elevated to generic status.

**Mindycrusta oepiki** sp. nov. (Figs 12A-P, 13A-B)

1911 *Psychoparia thielei*; Chapman, p. 316, pl. 58, fig. 10, non figs 2, 3, 5, 7.

1911 *Psychoparia minima*; Chapman, p. 318, pl. 58, fig. 6.

**Etymology.** After the late Dr A. A. Öpik, for his work on the genus and his prolific contributions to the knowledge of Australian Cambrian trilobites.

**Diagnosis.** A species of *Mindycrusta* with slightly tapering glabella; well impressed occipital furrow; long (sag.) occipital ring with strongly bowed posterior margin; lateral glabellar furrows effaced; short palpebral lobes situated opposite midlength or slightly anterior of midlength of glabella; relatively wide palpebral area, width (tr.) approximately 40% width of occipital ring; anterior branches of facial sutures converge gently anteriorly; narrow (tr.) pygidial axis almost reaching posterior border and containing eight axial rings; eight well developed pleural furrows extend to border furrow.
Fig. 12. Mindycrusta oepiki sp. nov. All specimens from type locality D-BSW1, unless otherwise stated. A, B, holotype cranium, CPC37366; A, dorsal view, x5; B, anterolateral view, x4; C, D, partial cranium, CPC37367; C, anterolateral view, x5; D, dorsal view, x8; E, F, partial cranium, CPC37368; E, dorsal view, x5; F, oblique anterolateral view, x6; G, partial cranium, dorsal view, CPC37369, x8.5; H, partial cranium, dorsal view, CPC37370, x8; I, partial cranium, dorsal view, CPC37371, x8; J, partial pygidium, dorsal view, CPC37374, x4; K, partial pygidium, dorsal view, CPC37375, x2.5; L, partial pygidium, dorsal view, CPC37376, x4; M, partial pygidium, dorsal view, CPC37377, x5; N, partial pygidium, dorsal view, CPC37378, x3.5; O, P, partial pygidium, from D-GG1, CPC37379; O, dorsal view; P, oblique posterolateral view; both x5.5.
Type material. Holotype: partial cranium, CPC37366 (Fig. 12A). Paratypes: 7 crania, CPC37367-37373 (Figs 12C-1, 13A-B); 6 pygidia, CPC37374-37379 (Fig. 12J-P).

Other material. 3 crania, 17 pygidia, CPC37380-37399.

Localities. D-BSW1 (type locality), D-GG1, D-GG2, D-GG3 and D-GG4.

Description. Cranidium trapeziform, strongly convex (sag., exsag.), sagittal length approximately 70% width (exsag.) along posterior margin. Glabella strongly convex (sag., exsag.), elevated above fixigenae; gently tapering forward with broadly rounded anterior; length (sag.) approximately 85% sagittal length of cranium. Axial and preglabellar furrows deep. Occipital furrow is well impressed, becoming narrower (exsag.) abaxially. Occipital ring long (sag.), strongly tapering abaxially, gently convex, with strongly bowed posterior margin. Lateral glabellar furrows effaced. Preglabellar field short (sag.), moderately downsloping. Anterior border short (sag.), moderately convex, separated from preglabellar field by deep anterior border furrow. Palpebral lobes short, situated opposite middle of auricles of glabella; low, faint eye ridges directed posteroventrally from anterolateral corners of glabella. Preocular areas of fixigenae slope evenly down to anterior border furrow. Palpebral areas downsloping abaxially, width (tr.) approximately 40% width of occipital ring. Posterior areas downsloping abaxially.


Librigena, hypostome and thorax unknown.

Pygidium semi-elliptical, gently convex, sagittal length approximately 60% width (tr.). Axis tapers moderately posteriorly, occupying approximately 85% of the sagittal length of the pygidium and almost reaching the posterior border; contains eight axial rings and a terminal piece; width (tr.) of anterior portion of axis is approximately 22% pygidial width. Short (sag.) articulating half ring. Axial furrows deep. Eight well developed pleural furrows extend to border furrow. Border furrow narrow and relatively shallow. Border is relatively narrow, of even width, and flat. Pygidial margin smooth.

Remarks. The new species of Mindycrusta, *M. oepiki* sp. nov., is easily distinguished from all other species previously described by Öpik (1967) based on the following cranial characteristics: (1) the anterior branches of the facial sutures converge gently anteriorly, whereas in other species the suture diverges anteriorly from the palpebral lobe before converging onto the anterior border; (2) the palpebral lobes are situated opposite the middle of the glabella; low, faint eye ridges directed posteroventrally from the anterolateral corners of the glabella, whereas the palpebral lobes of other species are situated opposite the anterior third of the glabella; (3) the palpebral area is relatively wide (tr.), i.e., the width is approximately 40% occipital ring width – other
species range in width from 12% to 29% occipital ring width; and (4) the glabella tapers forwards gently, whereas in other species the glabella is moderately to strongly tapered.

*Mindycrusta oepiki* sp. nov. appears to have an affinity with *M. notostena* Öpik, 1967. Apart from the differing cranial characteristics (see above), both have almost identical pygidia, i.e., both possess a narrow (tr.) axis that almost reaches the posterior border, eight axial rings, and a flat, narrow border of even width. The major difference is that *M. notostena* has effaced pleural fields. However, this may be the result of preservation, as varying degrees of effacement have been observed within single species, for example *M. oepiki* sp. nov. (Fig. 12J-P) and *M. mindycrusta* (Öpik 1967, pl. 11, figs 4-10; pl. 12, fig. 3).

Family TSINANIIDAE Kobayashi, 1933

**Tsinaniid gen. et sp. indet. 1** (Fig. 13C-D)

*Material.* 1 cranidium, CPC37400.

*Locality.* D-BSW1.

*Remarks.* As noted by Westrop (1992, p. 244), taxonomic treatment of effaced taxa is extremely difficult, and criteria other than effacement should be used as the basis for classification. The majority of Late Cambrian effaced 'pychoparioid' trilobites belong to the family Kingdomiidae and the Australasian family Tsinaniidae. Although the phylogenetic relationship between these families is unclear, one consistent morphological difference is the course of the anterior branch of the facial suture. In the Kingdomiidae, the anterior branch of the facial suture is convergent anteriorly, whereas in the Tsinaniidae the suture is divergent before rapidly converging anteriorly. In addition, the majority of kingdomiids possess a considerably wider (tr.) glabella than those of tsinaniids. For these reasons, the partial cranium from the Dolodrook is assigned to the Tsinaniidae, having possible affinities with *Shergoldia*. Of the species of *Shergoldia* recognised by Zhang & Jell (1987), *S. taianfusiens* (Endo) illustrated by Zhang & Jell (1987, pl. 89, figs 1-3), appears to be the only species with a bluntly pointed anterior cranial margin. Furthermore, both *S. taianfusiens* and the Dolodrook cranidium possess faint axial and preglabellar furrows, an effaced occipital furrow, very faint eye ridges, short palpebral lobes; and a flat, sagittally elongate anterior border. *S. taianfusiens* differs, however, in having a longer (sag.) preglabellar field with a broad prominent plectrum, and a wider (tr.) palpebral area.

**Tsinaniid gen. et sp. indet. 2** (Fig. 13E)

*Material.* 1 pygidium, CPC37401.


*Remarks.* The effaced nature of the Dolodrook pygidium from D-UCM suggests possible placement in the Tsinaniidae. This pygidium differs from other tsinaniids, however, in that the posterior end of the axis is truncate. The extremely faint, but broad pygidial border is similar to that of *Shergoldia*, implying that the Dolodrook pygidium possibly belongs to the cranium from D-BSW referred to as Tsinaniid gen. et sp. indet. 1.

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