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GR focus review

Global correlation of the early Cambrian of South Australia: Shelly fauna of the *Dailyatia odyssei* Zone

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ABSTRACT

A lack of well resolved biostratigraphic data has prevented robust regional and global correlation of lower Cambrian successions from South Australia. A new early Cambrian biostratigraphy, based on data derived from 21 measured stratigraphic sections and drill cores (11 described herein) reveals the abundance and diversity of shelly fauna from the Arrowie Basin, and the value of early Cambrian "small shelly fossils" (SSF) to biostratigraphic studies. Here we examine shelly fauna associated with the youngest of three recently established biozones, the *Dailyatia odyssei* Taxon Range Zone (hereafter *D. odyssei* Zone), and their correlative potential. The *D. odyssei* Zone features a diverse suite of tommotiids,

organophosphatic brachiopods, bradoriid arthropods, molluscs and phosphatic problematica. This fauna permits strong correlation (often at species-level) with other major early Cambrian terranes, particularly Antarctica, South China and Laurentia, and suggest a Cambrian Series 2, Stages 3–4 age for the *D. odyssei* Zone. Bradoriids have proven to be useful biostratigraphic tools. Four new species and three new genera are described herein: *Manawarra jonesi* gen. et sp. nov., *Eozhexiella adnyamathanha* gen. et sp. nov., *Acutobalteus sinuosus* gen. et sp. nov. and *Mongolitubulus decensus* sp. nov. The description of *Eohadrotreta* sp. cf. *zhenbaensis* represents the first occurrence of the acrotretoid brachiopod *Eohadrotreta* from Australia.

Keywords: Tommotiid, timescale, chronostratigraphy, biostratigraphy, small shelly fossils.

1.   INTRODUCTION

Early Cambrian shelly faunas are abundant, diverse and well preserved in the Arrowie Basin of South Australia. Betts et al. (2016b) formally defined three new biozones based on abundant shelly fossil material collected from 10 stratigraphic sections in the Arrowie Basin. These new shelly fossil zones range from Terreneuvian, Stage 2 to Series 2, Stages 3–4 (Betts et al., 2016b). The lowermost and entirely pre-trilobitic *Kulparina rostrata* Zone is succeeded by the *Micrina etheridgei* Zone. Overlying the *M. etheridgei* Zone is the *Dailyatia odyssei* Zone. The base of the oldest trilobite zone in Australia, the *Abadiella huoi* Zone (herein called the *Parabadiella huoi* Zone), occurs within the upper part of the *M. etheridgei* Zone. It is important to note that there is taxonomic and nomenclatural uncertainty surrounding the generic assignment of *Abadiella huoi* from South Australia. Jell (in Bengtson et al., 1990) considered *Abadiella* and *Parabadiella* to be synonyms, but we agree with Landing et al. (2013, p. 159) that the more appropriate name for this index species from Australia and South China is *Parabadiella huoi* (see also Betts et al., 2017), at least until the type species of *Abadiella*, *A. bourgini*, is restudied (including new, better preserved specimens from the type locality). Thus, the oldest trilobite zone in South Australia should now be referred to as the *P. huoi* Zone.

The base of the *Dailyatia odyssei* Zone and the faunal composition of the zone was originally based on range data compiled from four stratigraphic sections (Betts et al., 2016b, figs 2, 5, 8-9). This paper presents new biostratigraphic data from an additional nine measured stratigraphic sections and core data from two drill cores to more clearly define the boundaries and improve the correlative potential of the *D. odyssei* Zone. This biozone can now be clearly identified in subsurface drill cores and outcropping stratigraphic sections from the Stuart Shelf (west of the Arrowie Basin), as well as thick carbonate dominated successions across the central wedge of the Arrowie Basin, and the Benagerie Ridge in the east (Fig. 1). These new data provide a robust and comprehensive biostratigraphic database for defining the *D. odyssei* Zone in South Australia. In addition to AJX-M, MMT, WILK and

MOG (see Betts et al., 2016b), the *D. odyssei* Zone is present in (from west to east) the SCYW-791A drill core (Fig. 2), ER9 (identified with accessory taxa) (Fig. 3), DBS (Fig. 4), MMF (Fig. 5), 10MS (Fig. 6), BHG (Fig. 7), RC (Fig. 8), LMNB (Fig. 9), NB (Fig. 10), PIN (Fig. 11) sections, and the Yalkalpo-2 drill core (Fig. 12). Sections in the Donkey Bore Syncline (DBS, Fig. 4) and Ten Mile Creek (10MS, Fig. 6) are selected as reference sections for the biozone.

Diversity of shelly fauna in the *D. odyssei* Zone is high (for example, 53 taxa occur in the MMF section; Appendix 4). However, some of the accessory taxa common to the *D. odyssei* Zone (including key tommotiids, brachiopods, molluscs and bradoriids) range up from the underlying *M. etheridgei* Zone. Apart from the eponym, the first occurrence of the enigmatic taxon *Stoibostrombus crenulatus* Conway Morris and Bengtson in Bengtson et al., 1990 (see Skovsted et al., 2011b) is also used to define the base of the new biozone. Other accessory taxa in the *D. odyssei* Zone include the tommotiid *Kelanella* sp., the brachiopod *Curdus pararaensis* Holmer and Ushatinskaya in Gravestock et al., 2001, and the oldest acrotretoid in Australia, *Eohadrotreta* sp. cf. *E. zhenbaensis* (10MS section). Bradoriid arthropods also provide a very useful supplementary biostratigraphic signal. The *M. etheridgei* Zone and the overlying *D. odyssei* Zone can be readily discriminated based on distinctive assemblages of bradoriids associated with each zone (Fig. 13). Some of these taxa have wide geographic distributions that have great potential for intercontinental correlation.

2.   MATERIALS AND METHODS

Samples from the nine sections and two drill cores studied herein (Fig. 1) were processed using methods described in detail by Betts et al. (2016b). The Yalkalpo-2 drill core, located on the Benagerie Ridge, has been extensively investigated by previous authors for shelly fossils (including trilobites), acritarchs (Gravestock et al., 2001; Zang et al., 2001; Jago et al., 2002; Zang et al., 2007), and for lithological analyses (Gravestock, 1995). Drill core SCYW-791A intersects 70 m of fossiliferous Andamooka Limestone, but palaeontologically has only been the subject of an unpublished Honours thesis (Casey, 2005). Faunas from these drill cores have been reappraised as part of the biostratigraphic assessment herein. The remainder of the stratigraphic sections target the Mernmerna Formation at localities across the Arrowie Basin (Fig 1), including the Elder Range (ER9, Fig. 3), Donkey Bore Syncline (DBS, Fig. 4), Bunkers Range (MMF, Fig. 5), Bunkers Graben (10MS, Fig. 6),

4

Arrowie Syncline (BHG and RC, Figs. 7 and 8) and Mt. Chambers Gorge area (LMNB, NB and PIN, Figs. 9-11).

3.   STRATIGRAPHIC CONTEXT

This section discusses aspects of the relationships and lithologies of the key stratigraphic units intersected by the nine stratigraphic sections and two drill cores that are relevant to the *D. odyssei* Zone (documented herein). Betts et al. (2016b) provided a stratigraphic overview relating to the underlying *K. rostrata* and *M. etheridgei* zones. For more comprehensive reviews of the stratigraphy and lithology of the Cambrian deposits of the Hawker Group in the Arrowie Basin, see Haslett (1975), Clarke (1986a, b, c, 1990a, b, c), Gravestock and Hibburt (1991), Gravestock (1995), Zang et al. (2001, 2004), Ceglar et al. (2004), Jago et al. (2012) and Brock et al. (2016a,b).

3.1   Wirrapowie Limestone and adjacent units

       In defining the Wirrapowie Limestone type section, Haslett (1975, p. 217) stated that the "Wirrapowie Limestone…is overlain by Parara-type limestones. The topmost limit of the Wirrapowie Limestone is selected at the top of the uppermost algal stromatolite bed". However, Haslett (1975, p. 214, fig. 2) also noted that the "uppermost boundary of the Wirrapowie Limestone is somewhat gradational into the Parara Limestone [= Mernmerna Formation]". Critical in distinguishing these two units is the presence of stromatolitic horizons that are typically facies dependent, hence identification of the boundary between the Wirrapowie Limestone and the Mernmerna Formation outside of the type section is often ambiguous. In places such as the Chace Range, Elder Range (ER9, Fig. 3) and Arrowie Syncline (RC, Fig. 8), the fine grained, thin "ribbon" carbonates of the Wirrapowie Limestone transition into the darker, more flaggy carbonates of the lower Mernmerna Formation (Haslett, 1975). Where the iron-rich microstromatolitic beds that define the Flinders Unconformity (FU) on the platform are absent, the basal package of the Mernmerna Formation can interfinger with, or onlap the underlying Wilkawillina or Wirrapowie limestones (e.g. MOG section, Betts et al., 2016b, fig. 5).

       Previous mapping in the Angepena, Nepabunna and Arrowie synclines in the northern Flinders Ranges showed that the Mernmerna Formation hosts two finer-grained siliciclastic shale/siltstone members called the Midwerta Shale and the Nepabunna Siltstone (Coats et al.,

5

1973; Gravestock, 1995; Zang et al., 2004). Detailed sampling through the Wirrapowie Limestone and Mernmerna Formation in the BHG (Fig. 7) and RC (Fig. 8) sections indicates that some of the carbonates originally mapped as Parara Limestone (= Mernmerna Formation) in the southern and eastern Arrowie Syncline (Coats et al., 1973) potentially belong to the Wirrapowie Limestone based on lithologies. Whilst more detailed sedimentological study is required to confirm this, one of the key regional implications of this revision is that the Midwerta Shale could be a member of the Wirrapowie Limestone and not the Mernmerna Formation.

The boundary between the Wirrapowie Limestone and Mernmerna Formation occurs ~1150 m above the base of the BHG section, in the southern part of the Arrowie Syncline (Figs. 1, 7). In this section, the upper boundary of the *M. etheridgei* Zone is at BHG/1301.0, 1191.9 m above the base of the section (Appendix 6). The assemblage below this level is typical of the *M. etheridgei* Zone (including the eponym, *Askepasma toddense* Laurie, 1986, *Dailyatia ajax* Bischoff, 1976, *D. macroptera* (Tate, 1892) and *D. bacata* Skovsted, Betts, Topper and Brock, 2015) and is restricted to Wirrapowie, Wilkawillina, Ajax limestones elsewhere in the Arrowie Basin. The RC section on the eastern limb of the Arrowie Syncline consists of ~400 m of Wirrapowie Limestone and ~500 m of overlying Mernmerna Formation (Figs 1, 8). The Midwerta Shale is not developed in this region. The *M. etheridgei* Zone is manifest in the lower 498 m of the Wirrapowie Limestone and the *D. odyssei* Zone is 278.9 m thick (Fig. 8). *Micrina etheridgei* is usually restricted to the *M. etheridgei* Zone, but in the RC section, it occurs at RC/913.0, 123.4 m above the first occurrence of *D. odyssei*. This is the only occurrence of *M. etheridgei* within the *D. odyssei* Zone throughout all sections across the Arrowie Basin. This horizon is a heterogenous mix of mostly fragmentary and chaotically oriented skeletal grains that strongly suggests a degree of reworking (i.e., time averging) at this stratigraphic level in the RC section.

3.2   Mernmerna Formation and adjacent units

The Mernmerna Formation is interpreted as a carbonate ramp-slope facies, with dominant lithologies including dark coloured, often flaggy, calcareous mudstones and wackestones, with common spiculitic (mainly hexactinellid) horizons (Clarke, 1990b). Coarser-grained facies are usually rare, but do occur near shallow platform facies and can be laterally extensive (Clarke, 1990b). Large (decimetre-scale) allochthonous blocks derived

6

from older collapsed platform deposits (mainly Wilkawillina Limestone) are recorded in the Mernmerna Formation in the Bunkers Range at Donkey Bore Syncline (Clarke, 1986b; Gravestock & Cowley, 1995; Ceglar et al., 2004; Topper et al., 2007). No biohermal build-ups are recorded from the Mernmerna Formation, although the overlying Moorowie Formation in the Mt. Chambers region in the eastern Arrowie Basin has small archaeocyath-microbial bioherms associated with early coralomorphs (Lafuste et al., 1991; Fuller and Jenkins, 2007). Archaeocyaths are rare in the Mernmerna Formation and, when present, are usually transported or reworked from the older platformal deposits of the Wilkawillina Limestone (Clarke, 1990b).

Clarke (1986b, 1990b) originally described and defined three members of the Mernmerna Formation in the Bunkers Graben and Range (in ascending order): Six Mile Bore, Linns Springs and Third Plain Creek members; see Gravestock and Hibburt (1991), Gravestock (1995), and Brock and Paterson (2004). These members are variably developed across the Arrowie Basin, which, in part, relates to the FU (see Fig. 1; e.g., DBS, MMF, MMT and BALC [in Betts et al., 2016b]) (Gravestock and Cowley, 1995; Gravestock and Shergold, 2001). For example, in the DBS section (Fig. 4), the Six Mile Bore Member is absent and the Linns Springs Member rests disconformably on the Winnitinny Creek Member of the Wilkawillina Limestone. Further south, the Six Mile Bore and overlying Linns Springs members are both absent in the MMF section (Fig. 5) and the Third Plain Creek Member (being *P. bunyerooensis* trilobite Zone in age) rests disconformably on the Winnitinny Creek Member of the Wilkawillina Limestone (Fig. 5; see Paterson and Brock, 2007). In the BALC section (Betts et al., 2016b, fig. 7) in Balcoracana Creek (located 1 km north of MMF), the entire Mernmerna Formation and overlying Oraparinna Shale are missing and the red beds of the Billy Creek Formation rest disconformably on the Wilkawillina Limestone.

In the Arrowie Syncline, basinal highstand deposits also include the Nepabunna Siltstone, which in the BHG section is poorly fossiliferous, but contains taxa that range up from the underlying Wirrapowie Limestone and lower parts of the Mernmerna Formation (Fig. 7) (Gravestock and Hibburt, 1991). In the Mt. Chambers area in the eastern Flinders Ranges, the lower part of the Mernmerna Formation is relatively thin and rests with apparent conformity on the Wilkawillina Limestone (LMNB section, Fig. 9). In the LMNB section, the Mernmerna Formation is conformably overlain by highstand siliciclastic deposits of the Bendieuta Formation (Gravestock, 1995). The NB section (Fig. 10) intersects ~174 m of

Mernmerna Formation, overlain with apparent conformity by the Moorowie Formation, an archaeocyath-rich, oolitic sandy limestone (Fuller and Jenkins, 2007).

The lower part of the Mernmerna Formation is overlain by a variably developed arkosic unit, the Bunkers Sandstone, in the central and eastern parts of the Arrowie Basin (Gravestock and Cowley, 1995; Ceglar et al., 2004). In the DBS and 10MS sections located in the central part of the basin (Figs. 4, 6), the upper part of the Mernmerna Formation overlies the Bunkers Sandstone with apparent conformity. The upper Mernmerna Formation develops as typical dark, flaggy, micritic limestones with gradually increasing siliciclastic input. To the east and north, the Bunkers Sandstone is not developed and the upper Mernmerna Formation is overlain by the Oraparinna Shale (10MS, Fig. 6) (Gravestock and Hibburt, 1991). The Andamooka Limestone on the Stuart Shelf, west of the Arrowie Basin is a relatively thin micritic limestone. Drill core SCYW-791A intersects 169 m of Andamooka Limestone (Fig. 2).

4. *DAILYATIA ODYSSEI* ZONE

The *Dailyatia odyssei* Zone is present in the Andamooka Limestone, Mernmerna Formation and upper Ajax Limestone (Arrowie Basin), in addition to temporal equivalents (Parara Limestone and Heatherdale Shale) in the Stansbury Basin. The *D. odyssei* Zone has the highest shelly fossil diversity of any of the defined shelly fossil zones in South Australia (*sensu* Betts et al., 2016b), with up to 53 taxa in some sections (MMF, Appendix 4).

4.1 Lower boundary

Betts et al. (2016b) formally defined the lower boundary of the *Dailyatia odyssei* Zone at the first appearance of *Dailyatia odyssei* Evans and Rowell, 1990 (Fig. 14. A-L) or *Stoibostrombus crenulatus* (Fig. 14. J-M), whichever is lowest. The lower boundary of the *D. odyssei* Zone is also coincident with the upper boundary of the underlying *M. etheridgei* Zone (Betts et al., 2016b). The *D. odyssei* Zone is best represented in sections DBS (Fig. 4), where it occurs over 429 m of stratigraphic thickness, and 10MS (Fig. 6), where it is 500 m thick. These two sections are chosen as reference sections for the *D. odyssei* Zone.

8

Species of *Dailyatia* Bischoff, 1976 represent key faunal elements of the regional biostratigraphic scheme developed by Betts et al., (2016b), as they are abundant, well preserved and readily identifiable in the Arrowie Basin (Skovsted et al., 2015a). Ranges of *D. odyssei* and *S. crenulatus* have stratigraphic ranges that do not overlap with older *Dailyatia* species (see Skovsted et al., 2015a; Betts et al., 2016b) and so the first appearance of either can confidently be used to define the *D. odyssei* Zone.

The regional hiatus represented by the FU can obscure the relationship between the *D. odyssei* Zone and the preceding *M. etheridgei* Zone (Betts et al., 2016b). Key shelly taxa associated with the *M. etheridgei* Zone do not occur stratigraphically above the FU (see Betts et al., 2016b for discussion about the FU) and the *D. odyssei* Zone extends down to the top of the FU in those sections in which it is developed (e.g. DBS, Fig. 4; MMF, Fig. 5 and 10MS, Fig. 6 herein). The FU is not apparent everywhere across the Arrowie Basin, and in sections where it is not developed (e.g. ER9, Fig. 3; BHG, Fig. 7; RC, Fig. 8; Yalkalpo-2, Fig. 12 and AJX-M, fig. 2 in Betts et al., 2016b), the boundary between the *M. etheridgei* and *D. odyssei* zones occurs in transitional facies.

Betts et al. (2016b) demonstrated that the incoming of *D. odyssei* overlaps with the uppermost 3.4 m of the *P. huoi* trilobite Zone in the AJX-M section. *Dailyatia odyssei* ranges through the entire *Pararaia tatei* and *Pararaia bunyerooensis* trilobite zones, and into the lowermost part of the *Pararaia janeae* Zone in the DBS section (Fig. 4). The first appearance of *S. crenulatus* occurs in strata belonging to the *P. tatei* Zone in the AJX-M (Betts et al. 2016b, fig. 2), DBS (Fig. 4), 10MS (Fig. 6) and possibly the RC sections (Fig. 8). No specimens of *S. crenulatus* have been recovered from the *P. huoi* Zone.

4.2 Upper boundary

The upper boundary of the *D. odyssei* Zone is defined by the last occurrence of either *D. odyssei* or *S. crenulatus*, whichever is higher. *Stoibostrombus crenulatus* has not been recovered from the eastern part of the Arrowie Basin (Mt. Chambers area) in sections LMNB, NB and PIN, nor in Yalkalpo-2 core material. In reference section DBS, the last occurrence of *D. odyssei* occurs at sample horizon 684 m (= 562.3 m true thickness above the base of the section; Appendix 3), which is 14 m above the first appearance of trilobites *Atops rupertensis* Jell, Jago and Gehling, 1992 and *Serrodiscus gravestocki* Jell in Bengtson et al., 1990 that are

9

associated with the *P. janeae* Zone (Jell in Bengtson et al., 1990; Jago et al., 2006). The first occurrence of the trilobite *Hebediscina yuqingensis* (Zhang in Yin and Lee, 1978) occurs at the same stratigraphic level as the last occurrence of *D. odyssei* in the DBS section (Fig. 4). Whilst *P. janeae* has not been recovered from DBS, the presence of trilobites typically associated with this zone suggests the top of the *D. odyssei* Zone occurs in the lower part of the *P. janeae* Zone.

Limited data from the Stansbury Basin indicate that *S. crenulatus* may potentially range higher into younger (Toyonian-equivalent) beds, but these rare instances require further investigation and corroboration. For instance, Brock and Cooper (1993, fig. 5, fig. 8.4-8.6) illustrated a single sclerite of *S. crenulatus* [SADMW 10454] from Stansbury Town 1 drill core 10. 981.5-984.5 on Yorke Peninsula in "dark grey mottled limestone". This unit was identified as the Ramsay Limestone (Daily, 1968), as it contained *Redlichia* sp., "*Hyolithes*", "*Lingulella*", and "*Obolella*", which Brock and Cooper (1993) correlated with the Cambrian Stage 4 (Toyonian-equivalent) Wirrealpa Limestone in the Arrowie Basin. Gravestock et al. (2001, fig. 13) also recorded rare *S. crenulatus* from the Ramsay Limestone in the Cur-D1B core, as well as in the Stansbury and Coobowie limestones in the Port Julia 1A core (Gravestock et al., 2001, fig. 8).

4.3 Accessory taxa

4.3.1 Tommotiids, cambroclaves and problematic forms

Tommotiids are relatively common in the *D. odyssei* Zone, the majority of which range from the underlying *M. etheridgei* Zone. However, certain taxa occur exclusively within the *D. odyssei* Zone and so can be used as accessory taxa to identify the zone. For example, the camenellan tommotiid *Kelanella* sp. occurs within the *D. odyssei* Zone in DBS (Fig. 4), MMF (Fig. 5), BHG (Fig. 7) and RC (Fig. 8). *Kelanella* possesses a multi-element scleritome made up of five separate coniform and septate sclerite morphs (Devaere et al., 2014) (Fig. 14N-U). In the Arrowie Basin, *Kelanella* is represented by relatively rare but distinctive sclerite morphotypes that may be restricted to a single horizon (e.g. DBS, Fig. 4, MMF, Fig. 5, BHG, Fig. 7 and AJX-M, Betts et al., 2016b, fig. 2). Whilst fragmentary, this sclerite morphotype is interpreted as an element of the scleritome of an undescribed species of *Kelanella* (Fig. 14N-U). In the RC section, *Kelanella* sp. occurs in three horizons with a

10

total range of 50.6 m (all stratigraphic thicknesses are true thicknesses unless otherwise specified) within the Mernmerna Formation (Fig. 8, Appendix 7). In the BHG section, the horizon in which *Kelanella* sp. occurs is 18.8 m above the lower boundary of the *D. odyssei* Zone, equivalent to the *P. tatei* trilobite Zone. *Kelanella* sp. also occurs in *P. tatei* Zone-equivalent strata in the DBS section (Fig. 4). In the MMF section, *Kelanella* sp. co-occurs with the trilobite, *P. bunyerooensis*. This suggests that ithe entire range of *Kelanella* sp. overlaps with *D. odyssei* and spans most of the *P. tatei* and *P. bunyerooensis* trilobite zones.

In all but one of the sections documented here (i.e., 10MS, Fig. 6, Appendix 5), the stratigraphic range of *Cambroclavus absonus* Conway Morris in Bengtson et al., 1990 coincides with that of *D. odyssei*. In 10MS, *C. absonus* first occurs 9.3 m below the incoming of *D. odyssei*, at a poorly exposed level just above the FU that includes some faunal elements from the underlying *M. etheridgei* Zone. The mixed faunal signature and fragmentary nature of skeletal material suggests a degree of reworking at this level (Fig 6). In the AJX-M section (Betts et al., 2016b, fig. 2), the first occurrence of *C. absonus* occurs in the same horizon as *D. odyssei. Cambroclavus absonus* also occurs in the *P. bunyerooensis* Zone in the MMF section (Fig. 5) (Topper et al., 2009), and overlaps with trilobites of the *P. janeae* Zone in the DBS section (Fig. 4) (Topper et al., 2007). *Cambroclavus absonus* also has a short range of 2.9 m in the *D. odyssei* Zone in the Andamooka Limestone on the Stuart Shelf (SCYW-791A, Fig. 2).

The tubular form, *Anabarites sexalox* Conway Morris and Bengtson in Bengtson et al., 1990 is restricted to the *D. odyssei* Zone in the MMF (*P. bunyerooensis* Zone), 10MS and NB sections, while other problematic taxa often associated with the *D. odyssei* Zone include a number of unidentified protoconodont taxa (Fig. 16R-U; 16Y-AA). These spinose forms need formal taxonomic treatment and most range from the underlying *M. etheridgei* Zone (e.g., ER9, Fig. 3).

4.3.2 Brachiopods

Brachiopod taxa that first appear in the preceding *M. etheridgei* Zone are also common in the *D. odyssei* Zone. In particular, *Eoobolus*, *Karathele* (=*Schizopholis*) *yorkensis*, *Kyrshabaktella davidii*, *Eodicellomus elkaniformiis* and *Minlatonia tuckeri* Holmer and Ushatinskaya in Gravestock et al., 2001 (see Betts et al. 2016b, figs 16-17). *Eoobolus* is a

11

common faunal component of both the *M. etheridgei* and *D. odyssei* zones. The genus is widespread and long-ranging (up to Stage 5) (Ushatinskaya and Korovnikov, 2014). Currently, *Eoobolus* is a "wastebasket" taxon (Betts et al., 2016b), and specimens recovered for this study probably represent more than one species. Re-evaluation of *Eoobolus* from South Australia is required to establish species, and any biostratigraphic signals they may have. *Eoobolus*, *Karathele yorkensis* and *Kyrshabaktella davidii* range throughout much of the *D. odyssei* Zone, and extend beyond the upper boundary of the zone in the DBS reference section. *Askepasma toddense* from the preceding *M. etheridgei* Zone also ranges into the *D. odyssei* Zone (e.g. 10MS section – Appendix 5; NB section – Appendix 9; MOG section in Betts et al., 2016b, fig. 5), although the rarity of these occurrences in allodapic carbonates typical of the Mernmerna Formation could be the result of transport by turbidites.

While shell remains are usually fragmentary, the stem-group brachiopod *Mickwitzia* sp. (Skovsted et al., 2009b) occurs exclusively within the *D. odyssei* Zone in three sections (AJX-M, SCYW-791A and MMF). The total range of *Mickwitzia* sp. in the AJX-M section is 33.6 m (true thickness) and approximates that of the trilobite *P. tatei* (Betts et al., 2016b, fig. 2). Occurrence in the MMF section extends the range of *Mickwitzia* sp. into the *P. bunyerooensis* Zone (Fig. 5). *Mickwitzia* sp. also occurs in a single layer of the Andamooka Limestone, 99.15-99.25 m below the top of the SCYW-791A drill core (Fig. 2).

Additionally, *Curdus pararaensis* (Fig. 15P-V) has a range that is also consistently restricted to the *D. odyssei* Zone (or inferred *D. odyssei* Zone) in five stratigraphic sections: AJX-M (Betts et al., 2016b, figs 2 and 21P-S), SCYW-791A (Fig. 2), DBS (Fig. 4), MMF (Fig. 5) and 10MS (Fig. 6). In the AJX-M section, it has a range through the Ajax Limestone that is identical to *Mickwitzia* sp. (33.6 m true thickness) and approximates the *P. tatei* Zone. *Curdus pararaensis* is most abundant in the MMF section where its total range is 22.14 m true thickness (*P. bunyerooensis* Zone; Appendix 5), and its first appearance occurs in the same horizon as that of *Stoibostrombus crenulatus*. In the SCYW-791A drill core, *C. pararaensis* extends 1 m above the apparent upper boundary of the zone, although the zone is likely to extend higher in this core (Fig. 2). In the 10MS reference section, *C. pararaensis* is restricted to the *D. odyssei* Zone and ranges over 83.3 m, through the Linns Springs and Third Plain Creek members of the Mernmerna Formation (Fig. 6, Appendix 5).

The oldest acrotretoid taxon known from Australia, *Eohadrotreta* sp. cf. *E. zhenbaensis* (Fig. 15A-O) is only known from the 10MS section (Appendix 5). In this

section, *Eohadrotreta* sp. cf. *E. zhenbaensis* occurs within the upper parts of the *D. odyssei* Zone, and extends 80.4 m above the top of the zone (Fig. 6).

4.3.3. Molluscs

Many taxa have long ranges that encompass much of the *M. etheridgei* Zone and overlying *D. odyssei* Zone. These include species of *Pelagiella*, *Mackinnonia*, *Anabarella* (Betts et al. 2016b, fig. 18) and abundant hyoliths. Halkieriid sclerites are also common in the *D. odyssei* Zone. The isolated cap-shaped shells of the halkieriid *Oikozetetes mounti* Jacquet, Brock and Paterson, 2014 have been recovered from sections MMF (Fig. 5) and NB (Fig. 10) at levels that correlate with the *P. bunyerooensis* trilobite Zone and *D. odyssei* Zone (Jacquet et al., 2014). Distribution of molluscan steinkerns is strongly affected by taphonomic filters associated with phosphate accumulation that lead to a bias in preservation and therefore stratigraphic occurrence (Jacquet and Brock, 2015; Betts et al., 2017). Some carbonate layers especially those associated with hardgrounds/firmgrounds have excessive phosphate which dramatically skews preservation potential in favour of steinkern production leading to very high abundance and/or diversity (e.g. in section MMF, Fig. 5, Appendix 4). Adjacent strata devoid of phosphate rarely preserve molluscan material. Molluscs may also be preserved as replaced (phosphatised or silicified) shells or with phosphatic coatings (Fig. 17A-C, E-F; Betts et al. 2016b, fig. 18). The episodic nature of helcionelloid (plus hyolith and halkieriid) preservation and the difficulty of accurately identifying morphospecies based predominantly on steinkern material raises considerable challenges for use in early Cambrian biostratigraphy (see discussion by Jacquet and Brock [2015] and Betts et al. [2016b]). Despite this, it is true that some distinctive stem-group molluscs (including helcionelloids) are extremely widespread in the early Cambrian (e.g. *Watsonella*, *Pelagiella*, *Anabarella*, *Yochelconiella*) and may prove important in defining chronostratigraphic boundaries (Peng et al., 2012). However, in the current regional scheme, they are utilised as accessory taxa only.

4.3.4 Bradoriids

Bradoriids restricted to the *D. odyssei* Zone include many of the taxa described by Topper et al., (2007), such as *Hipponicharion australis* Topper, Skovsted, Brock and Paterson, 2007, *Mongolitubulus squamifer* Missarzhevsky, 1977, *Mongolitubulus unispinosa* Topper, Skovsted, Brock and Paterson, 2007, and *Onagrocharion tuberosis* Topper, Skovsted, Brock and Paterson, 2007. However, most of these taxa have been recovered only from the DBS section, so appraisal of their true stratigraphic ranges is difficult.

Specimens assigned to *Zepaera* are often extremely abundant in strata associated with the *D. odyssei* Zone; for instance, in the AJX-M (Topper et al., 2011b, fig 7H) and MMF sections (Skovsted et al., 2006, fig. 11A-G). Close inspection of the shields reveals the likely presence of at least two separate taxa, but detailed taxonomic assessment is required to confirm this suggestion. At this stage, a conservative approach is taken and we follow Skovsted et al. (2006) and Topper et al. (2011b) in simply referring to these shields as *Zepaera* sp.

Other bradoriid taxa associated with the *D. odyssei* Zone include *Acutobalteus sinuosus* gen. et sp. nov. (Fig. 19A-G), which is found in single horizons in the 10MS reference section (10MS/130.0, 109.7 m, true thickness above the base of the section; Fig. 6), and the MMF section (MMF/49.7, 28.51 m above the base of the section; Fig. 5). Material of *A. sinuosus* from the NB section in Chambers Gorge is well preserved (Fig. 19A-G), and specimens occur over a stratigraphic range of 0.5 m in the upper Mernmerna Formation (NB/66.6, 47.0 m to NB/67.3,47.5 m, true thickness; Fig. 10). This taxon also occurs at 10MS/130.0 (118.8 m above the base of the section) in the Linns Springs Member of the Mernmerna Formation (Fig. 6). These occurrences suggest the total stratigraphic range of *A. sinuosus* gen. et sp. nov. in the Arrowie Basin encompasses the *P. tatei* and *P. bunyerooensis* zones within the *D. odyssei* Zone.

Specimens of *Jixinlingella* sp. occur in three sections. Material from MOG/551.5 (Betts et al., 2016b, appendix 4 as "Haoiid indet."; Fig. 19M) and LMNB/35.3 and LMNB/45.9 (Figs. 9, 19H, J) is restricted to the *D. odyssei* Zone. The single specimen recovered from DBS/102.0 (Figs. 4, 19I) occurs 43.9 m below the first occurrence of *D. odyssei*, in strata relatively barren of age-diagnostic fossils, but likely to represent the *D. odyssei* Zone. Further sampling through these lower beds is required to accurately identify the

lower boundary of the zone at the DBS section and the total stratigraphic range of *Jixinlingella* sp.

Some bradoriid taxa have a first occurrence in the *M. etheridgei* Zone and range up into the overlying *D. odyssei* Zone. *Albrunnicola bengtsoni* Hinz-Schallreuter, 1993, for example, ranges from the upper part of the *M. etheridgei* Zone in the RC section (Fig. 8), but is known from the overlying *D. odyssei* Zone in sections MMF (Fig. 5; see also Skovsted et al., 2006), 10MS (Fig. 6), MOG, BALC (Betts et al. 2016b, figs 5, 7) and DBS (Topper et al., 2007; Fig. 14). *Albrunnicola bengtsoni* typically co-occurs with *Lapworthella fasciculata*, *Eoobolus*, and *Karathele yorkensis*, as well as steinkerns of *Pelagiella* sp. and *Mackinnonia* sp., which all range from the *M. etheridgei* Zone into the *D. odyssei* Zone.

A single specimen of *Spinospitella coronata* occurs in the *M. etheridgei* Zone in the ER9 section (Fig. 3, Topper et al., 2011b, Fig. 7N), but ranges into the *D. odyssei* Zone in the ER9, BALC, 10MS, MMF, and DBS sections. In reference section 10MS, *S. coronata* has a total range of 168.9 m, with a first occurrence at 10MS/86-87, 60.3 m (true thickness) above the lower boundary of the *D. odyssei* Zone.

Manawarra jonesi gen. et sp. nov. was previously described as *Euzepaera* sp. by Skovsted et al. (2006) and Topper et al. (2007), based on fragmentary material from the MMF and DBS sections, respectively. Most of the previously illustrated specimens from the MMF and DBS sections are clearly conspecific with abundant material from seven other sections (ER9, BHG, RC, NB, PIN, 10MS, MOG). However, close examination of all shields reveals that a small number of subtriangular shields from the MMF section referred to as *Euzepaera* sp. (e.g., Skovsted et al., 2006, fig. 12A,B) are not conspecific with *M. jonesi* gen. et sp. nov. and probably represent a separate taxon (see Taxonomic discussion below). Topper et al. (2007) noted the long stratigraphic range of *M. jonesi* gen. et sp. nov.in the DBS section. Additional data presented herein suggest that the range of *M. jonesi* gen. et sp. nov. is even longer, extending from the *M. etheridgei* Zone into the *D. odyssei* Zone. The stratigraphic range of *M. jonesi* gen. et sp. nov. in the DBS reference section is 503.3 m true thickness, with the lowermost and uppermost occurrences extending beyond the defined lower and upper boundaries of the *D. odyssei* Zone, respectively (Fig. 4). In the ER9 section, *M. jonesi* gen. et sp. nov.is restricted to the *M. etheridgei* Zone (Fig. 3; Topper et al., 2011b). It also occurs in the *M. etheridgei* Zone in the BHG section (BHG/293.0, 154.5 m true thickness above the defined lower boundary of this zone) ranging up to the lower boundary of

15

the *D. odyssei* Zone (Fig. 7; Appendix 6). In the RC section, *M. jonesi* gen. et sp. nov. ranges through both the *M. etheridgei* and the *D. odyssei* zones (RC/140.5 – RC/1119.0, a total range of 687.7 m) (Fig. 8).

5. CORRELATION

5.1 Regional correlation

5.1.1 Western Stansbury Basin, Yorke Peninsula

Skovsted et al. (2015a, p. 63) noted that fragmentary specimens referred to *Dailyatia* sp. by Skovsted and Brock (in Paterson et al., 2007) from the Koolywurtie Limestone Member of the Parara Limestone in Horse Gully are probably *D. odyssei* based on their ornament and the overhanging crest of the central plica. *Stoibostrombus crenulatus* has been reported in the Parara Limestone from the SYC-101, CD-2, and Port Julia-1A drill cores (Gravestock et al., 2001) where it occurs with taxa commonly from the *D. odyssei* Zone in the Arrowie Basin sections, such as the helcionelloid molluscs *Mackinnonia rostrata* (Zhou & Xiao, 1984) and *Pelagiella subangulata* (Tate, 1892) and brachiopods such as *Eoobolus*, *Minlatonia tuckeri* and *Eodicellomus elkaniiformis*. Gravestock et al. (2001, fig. 7) reported rare occurrences of *Dailyatia ajax* in the Parara Limestone above the disconformity surface (in horizons HG1 and HG9) at Horse Gully, but none of the specimens were illustrated and re-collection and detailed examination of samples through this interval of the Parara Limestone did not reveal any specimens of *Dailyatia*. It seems likely that if *Dailyatia* is present in the Parara Limestone above the regional disconformity at Horse Gully, it is more likely to represent *D. odyssei*. The lower 1–2 m of Parara Limestone immediately above the disconformity also contains *Stoibostrombus crenulatus* (in sample 6429RS106) and the trilobite *Yorkella australis* (Jell in Bengtson et al., 1990), strongly suggesting that the lower part of the Parara Limestone at Horse Gully correlates with strata of *D. odyssei* Zone age in the Arrowie Basin, and that the karstic microstromatolitic disconformity is time-equivalent to the FU in the Arrowie Basin.

Curdus pararaensis occurs in the *D. odyssei* Zone of the Ajax Limestone (Betts et al. 2016b, fig. 1), Andamooka Limestone (SCYW-791A, Fig. 1) and the Mernmerna Formation (MMF, Fig. 5; 10MS, Fig. 6). Paterson et al. (2007, fig. 3F-J) also reported an indeterminate obolid brachiopod from the Koolywurtie Limestone Member (Parara Limestone), which is

16

considered synonymous with *C. pararaensis* herein. In addition, the presence of probable *D. odyssei* and *S. crenulatus* in the Koolywurtie Limestone Member at Horse Gully (Paterson et al., 2007; Skovsted et al., 2015a), in addition to *S. crenulatus* in the Cur-D1B core (at 278.5 m) reported by Gravestock et al. (2001, fig. 13) confirms correlation with the *D. odyssei* Zone.

Cambroclavus absonus is reported from the Parara Limestone in the Horse Gully section by Bengtson et al. (1990) and Gravestock et al. (2001). Bengtson et al. (1990, fig. 4) record a short range for *C. absonus* approximately 17 m above the disconformable surface that separates the Kulpara and Parara limestones. Here it occurs with the trilobite *P. tatei* and an abundant shelly fauna including *Lapworthella fasciculata*, *Anabarites sexalox*, *Mackinnonia davidii*, *Stenotheca* cf. *drepanoida*, *Anabarella australis*, *Pelagiella subangulata*, hyoliths such as *Triplicatella disdoma* Conway Morris in Bengtson et al., 1990, and halkieriid sclerites. Gravestock et al. (2001, fig. 7) reported *C. absonus* from sample HG0, less than a metre above the disconformity surface in Horse Gully (Gravestock et al., 2001, fig. 7). Betts et al. (2016b) correlated this horizon with the *D. odyssei* Zone. The record of *S. crenulatus* from the Parara Limestone at Horse Gully in horizon 6429RS106 by Bengtson et al. (1990), immediately above the disconformity surface, is strongly indicative of the *D. odyssei* Zone at this level.

The globally distributed macromollusc *Marocella mira* Geyer, 1986 (see discussion below), occurs sporadically across numerous localities in the Arrowie Basin, within the mid-upper *D. odyssei* Zone in sections MMF (Fig. 5; Topper et al., 2009), ER9 (Fig. 3) and CR2 (Jacquet and Brock, 2015). Topper et al. (2009) discussed the reported occurrence of *Marocella australica* (=*M. mira*) in the upper Parara Limestone in Horse Gully (Stansbury Basin) at a level that also contained *P. tatei* (Gravestock et al., 2001); this would also fall within the *D. odyssei* Zone.

5.1.2 Amadeus Basin, central Australia

Bengtson et al. (1990, fig. 68A, B) illustrated a single (conjoined) specimen of *C. absonus* from the Todd River Dolostone in the Amadeus Basin. This specimen is severely abraded, and is missing diagnostic features such as a spine or spine base, making assignment to *C. absonus* questionable. Presence of *M. etheridgei* and *A. toddense*, in addition to *D. ajax* and *Eccentrotheca* sp. (Laurie, 1986), correlate the Todd River Dolostone with strata

17

containing faunas of the *M. etheridgei* Zone in the Arrowie Basin (Betts et al., 2016b).
Cambroclavus absonus is restricted to the *D. odyssei* Zone in the Arrowie Basin, so the
occurrence in older strata in the Amadeus Basin remains questionable. Further sampling is
required to clearly identify the taxon and define its biostratigraphic range.

5.2   Global correlation

Tommotiids, brachiopods, molluscs, and bradoriids documented from the *D. odyssei*
Zone in South Australia, in addition to previously documented, contemporaneous trilobite
assemblages (Jell in Bengtson et al., 1990; Paterson & Brock, 2007), provide some measure
of correlation with strata in Antarctica, Avalonia, Baltica, China, Laurentia, Siberia and West
Gondwana. Reliable correlations are enabled by more globally distributed species by this
time in the Cambrian. However, sustained provincialism and difficulties associated with
identification of taxa that bore multi-element scleritomes makes fine-scale biostratigraphic
correlation very difficult at regional and especially global scales. We emphasise the
integration of multi-proxy data to strengthen biostratigraphic correlation. These
biostratigraphic data (herein) are complimented by carbon isotope chemostratigraphy from
the same sections and calibrated CA ID-TIMS radiometric dates that will be presented in a
separate study.

5.2.1 South China

The *Dailyatia odyssei* Zone spans an interval from the uppermost *P. huoi* trilobite
Zone through the *P. tatei* and *P. bunyerooensis* zones and into the basal part of the *P. janeae*
Zone in the Arrowie Basin (Fig. 13). Paterson and Brock (2007) established clear correlation
of the *P. tatei* and *P. bunyerooensis* zones with the *Wutingaspis-Eoredlichia* Interval Zone
(Qiongzhusian) in South China, based on the co-occurrence of *Eoredlichia* Chang in Lu and
Dong 1952 (including the presence of *E. shensiensis* in both regions)*, Wutingaspis,* and
Yunnanocephalus (Fig. 21); see additional discussion by Betts et al. (2017).

Brachiopods also enable correlation between South Australia and South China
(Steiner et al., 2007; Yang et al., 2015; Zhang et al., 2015). In Zhenba County, South Shaanxi
Eoobolus aff. *viridus* and *Kyrshabaktella*? sp. occur in the Xihaoping Member of the

18

Dengying Formation and in the Shuijingtuo Formation (*Cambroclavus fangxianensis-Rhombocorniculum cancellatum* Assemblage Zone) (Li and Holmer, 2004; Yang et al., 2015). In the Arrowie Basin, *Eoobolus* and *Kyrshabaktella davidii* occur throughout the upper *M. etheridgei* Zone and into the *D. odyssei* Zone. *Eohadrotreta zhenbaensis* also occurs in the Shuijingtuo Formation in the Three Gorges area in western Hubei and in southern Shaanxi (Zhang et al., 2015). Zhang et al. (2015) state that lingulid-acrotretoid assemblages are not evident in the Qiongzhusian and instead suggest a Stage 4/Canglangpuian age for this part of the Shuijingtuo Formation. This is consistent with the occurrence of *Eohadrotreta* sp. cf. *E. zhenbaensis* and lingulids such as *K. yorkensis* and *K. davidii* in the upper *D. odyssei* Zone in the 10MS section (Fig. 6).

Microdictyon effusum, Cambroclavus fangxianensis and the mollusc *Beshtashella tortillis* also occur in the Shuijingtuo Formation in southern Shaanxi (*Cambroclavus fangxianensis-Rhombocorniculum cancellatum* Assemblage Zone) (Yang et al., 2015). *Microdictyon* sclerites are associated with both the *M. etheridgei* and *D. odyssei* zones in South Australia (Betts et al., 2016b), whereas *Cambroclavus absonus* and *Beshtashella tortillis* only occur within the *D. odyssei* Zone (AJX-M, Betts et al., 2016b; SCYW-791A, Fig. 2; DBS, Fig. 4; MMF, Fig. 5; 10MS, Fig. 6; MMF, Topper et al., 2009). In South China, the *C. fangxianensis-R. cancellatum* Assemblage Zone is equivalent to the *Pelagiella subangulata* Taxon-range Zone and the *Parabadiella huoi* and *Wutingaspis-Eoredlichia* trilobite zones which equates to the *Parabadiella huoi, Pararaia tatei* and *Pararaia bunyerooensis* zones in South Australia. The Chinese zones are broadly equivalent to the upper *M. etheridgei* and *D. odyssei* zones (Yang et al., 2015; Fig. 21 herein). In Shaanxi, *Rhombocorniculum cancellatum* has been recovered from the Xihaoping Member and the Shuijingtuo Formation (Yang et al., 2015), further reinforcing correlation between the *D. odyssei* Zone in South Australia and the *R. cancellatum – C. fangxianensis* Assemblage Zone in China.

At the generic level, bradoriid assemblages from South Australia also share close similarities with those from South China (Shu, 1990; Shu and Chen, 1994; Hou et al., 2002; Zhang, 2007; Topper et al., 2011b; Yang et al., 2015). *Albrunnicola, Haoia, Hipponicharion, Jixinlingella, Liangshanella, Mongolitubulus*, and *Zepaera* are all recorded from the *D. odyssei* Zone of South Australia, as well as from the *Eoredlichia-Wutingaspis* Zone of South China (Hou et al., 2002; Zhang, 2007; Topper et al., 2011b). However, in South Australia,

Albrunnicola, *Jixinlingella*, *Liangshanella*, *Mongolitubulus*, and *Zepaera* have first occurrences (albeit different species, except *Albrunnicola bengtsoni*) in the underlying *M. etheridgei* Zone (Fig. 13), with *Liangshanella circumbolina* in particular occurring in pre-*P. huoi* trilobite Zone strata. This demonstrates that many of these long-ranging bradoriids have limited use as correlative tools at the generic level, and that the endemic species from the *M. etheridgei* Zone in South Australia are likely to be some the oldest representatives of these genera, at least in Gondwana.

Other generic level connections between South China and Australia include the bradoriids *Neokunmingella* and *Hipponicharion*. In South China, *Neokunmingella* cf. *minuta* ranges from the *Eoredlichia-Wutingaspis* Zone (Qiongzhusian) to the *Palaeolenus* Zone (Canglangpuan) (Hou et al., 2002); the latter zone equates to the *P. janeae* trilobite Zone in South Australia (Paterson & Brock, 2007). *Neokunmingella shuensis* is also recorded from the *Eoredlichia-Wutingaspis* Zone in South China (Zhang, 2007). In the Arrowie Basin, *Neokunmingella moroensis* is restricted to the *M. etheridgei* Zone in the MORO and MOG sections (Betts et al., 2016b; Fig. 13). Other hipponicharionid taxa from South China include *Hipponicharion cuii* from the Shuijintuo Formation (*Eoredlichia-Wutingaspis* Zone) (Zhang, 2007) and *Hipponicharion qianensis* from the mid-Cambrian Gaotai Formation (*Pagetia* Biozone) (Zhang, 2007). *Hipponicharion australis* occurs in the *P. janeae* Zone (= upper *D. odyssei* Zone) in the DBS section, although it is rare (Topper et al., 2007). Thus, *Neokunmingella* and *Hipponicharion* appear to have long stratigraphic ranges and are therefore unsuitable for high-resolution biostratigraphic correlation.

Haoiid bradoriids also provide broad-scale correlations. *Jixinlingella* was known only from South China before *J. daimonikoa* was recently described from South Australia (Betts et al., 2014). The type species, *J. clithrocosta*, was described from the Shuijingtuo Formation (*Eoredlichia-Wutingaspis* Zone), Shaanxi (Lee, 1975; Zhang, 2007). In the Arrowie Basin, *J. daimonikoa* is restricted to the *M. etheridgei* Zone, although a second species, *Jixinlingella* sp. (Fig. 19H-M), occurs in the MMF, DBS, MOG and LMNB sections within the *D. odyssei* Zone. *Haoia shaanxiensis* is the only bradoriid reported from the Xihaoping Member, Dengjing Formation (*C. fangxianensis – R. cancellatum* Assemblage Zone) in southern Shaanxi (Yang et al., 2015). A comparable form (*Haoia* cf. *shaanxiensis*) was recovered from the *D. odyssei* Zone (= *P. bunyerooensis* trilobite Zone) in the MMF section (Fig. 5, Skovsted et al. 2006, fig. 13A-D).

A bradoriid-phosphatocopine assemblage from the Shuijingtuo Formation in Zhenba County, Shaanxi (*C. fangxianensis* – *R. cancellatum* Assemblage Zone) (Yang et al., 2015) permits species level correlation with South Australian faunas. This includes the phosphatocopid *Dabashanella hemicyclica* (MMF, Topper et al., 2009, fig. 3; AJX-M, Topper et al., 2011b, fig. 7O; Fig. 5) and the bradoriid *Beyrichona chinensis* Shu, 1990. According to Topper et al. (2011b, p. 317), specimens of *B. chinensis* illustrated by Zhang (2007, pl. 17, figs. 9-16) are considered to be conspecific with *Albrunnicola bengtsoni*. However, in South Australia, these species are not restricted to the *D. odyssei* Zone, but range from the upper *M. etheridgei* Zone in numerous sections (AJX-M, ER9, DBS, BALC, MMT/MMF, 10MS, RC, PIN; see Fig. 13). The assemblage from the Shuijingtuo Formation (Yang et al., 2015) also includes *Parahoulongdongella bashanensis* (Shu, 1990). In the Xiaoyangba section in Zhenba County, *P. bashanensis* co-occurs with *Tsunyidiscus niutitangensis*, which correlates with the lower *Wutingaspis-Eoredlichia* Interval Zone of South China (Steiner et al., 2007). In the Arrowie Basin, *P. bashanensis* is restricted to the *M. etheridgei* Zone, including the *P. huoi* trilobite Zone (Fig. 13).

5.2.2 North China

A diverse fauna of micromolluscs and small shelly fossils is known from the Xinji Formation of North China (He et al., 1984; Zhou and Xiao, 1984; Li et al., 2015; Hao et al., 2016 and references therein). Li et al. (2015) and Hao et al. (2016) reported *Cambroclavus absonus* Conway Morris in Bengtson et al., 1990 from the Xinji Formation. In the AJX-M section (Betts et al., 2016b, fig. 2), *C. absonus* and *D. odyssei* first occur in the same horizon (which overlaps with the *P. huoi* Zone), and range into the *P. tatei* Zone. In MMF (Fig. 5, Topper et al., 2009), *C. absonus* occurs within the *P. bunyerooensis* Zone. In the DBS section (Fig. 4), *C. absonus* occurs 6.6 m above the first occurrence of *Atops rupertensis* and *Serrodiscus gravestocki*, suggestive of the *P. janeae* Zone. These South Australian occurrences span the *D. odyssei* Zone and allow strong correlation with the *C. fangxianensis* – *R. cancellatum* Assemblage Zone on the North China Platform (Li et al., 2015, fig. 5). The shelly fauna from the Xinji Formation also includes a range of other taxa similar or conspecific with South Australian forms (Hao et al., 2016). This includes the micromolluscs *Anabarella drepanoida, Pelagiella madianensis, Mackinnonia rostrata, Yochelcionella chinensis, Pojetaia runnegari, Marocella* sp. and *Xianfengella* sp., in addition to the

21

tianzhushanellid *Apistoconcha siphonalis* and the trilobite *Estaingia* sp. (Zhou & Xiao 1984; Hao et al., 2016), all of which permit correlation with the *D. odyssei* Zone.

Cupitheca holocyclata has recently been described from South Australia and North China (Skovsted et al., 2016). In North China, *C. holocyclata* has been recovered from the Xinji Formation in the Shangwan section (Luonan County, Shaanxi) and in the Sanjianfang section (Yexian County, Henan) on the North China Platform (Pan et al., 2016, Skovsted et al., 2016). *Cupitheca holocyclata* is now known from several Cambrian palaeocontinents during Cambrian Stages 3-4 (Skovsted et al., 2016). However, accurate species determination may be difficult due to inconsistent preservation of the calcium carbonate shell (Jacquet and Brock, 2015), hence the stratigraphic ranges of some *Cupitheca* taxa remain to be elucidated.

5.2.3 Siberia

Kouchinsky et al. (2015) described a diverse shelly fauna from the lower Cambrian Emyaksin Formation in northern Siberia. This assemblage shares many similarities with the South Australian faunas, at least at the generic level, but additional proxies are required to establish robust correlation. The upper part of the Emyaksin Formation contains a fauna that includes the molluscs *Mackinnonia anabarica*, *Triplicatella* spp., and *Yochelcionella* cf. *Y. greenlandica*, in addition to the tommotiid *Lapworthella dentata*, and the ecdysozoans *Hadimopanella knappologica*, *Microdictyon* cf. *rhomboidale*, and *Mongolitubulus spinosus*. The age of this assemblage is equivalent to the *Delgadella*, *Judomia* and *Erbiella* zones (Atdabanian to earliest Botoman). *Rhombocorniculum cancellatum* was also recovered from upper levels in Sections 3, 6 and 7 (= *Judomia* Zone) in the Emyaksin Formation (Kouchinsky et al. 2015, fig. 2), permitting a correlation with the *C. fangxianensis – R. cancellatum* AZ in China and, in turn, with the *D. odyssei* Zone in South Australia. The tommotiids *Camenella garbowskae* and *Lapworthella* cf. *L. tortuosa* are part of a low diversity assemblage in the lower parts of the Emyaksin Formation (equivalent to the Tommotian *Dokidocyathus regularis* archaeocyath Zone) (Kouchinsky et al., 2015, fig. 2). In the Arrowie Basin, *Camenella reticulosa* and *Lapworthella fasciculata* occur in both the *M. etheridgei* and *D. odyssei* zones. Thus, it is reasonable to suggest that the "lower" (Tommotian; *D. regularis* Zone) and "upper" (Atdabanian–Botoman; *Delgadella* to *Erbiella* zones) shelly assemblages of the Emyaksin Formation are approximately age-equivalent to

22

the South Australian *M. etheridgei* Zone and *D. odyssei* Zone assemblages, respectively (Fig. 21).

The bradoriid *Liangshanella*? *sayutinae* and a suite of micromolluscs similar to those from South Australia have been recorded from the Bystraya Formation (Atdabanian – Botoman) in the Trans-Baikal region (Melnikova, 1988; Melnikova et al., 1997; Parkhaev, 2004). The micromolluscs include forms such as *Anabarella tshitaensis* Parkhaev, 2004, *Pelagiella adunca* Missarzhevsky, 1966, *Pojetaia runnegari*, *Stenotheca transbaikalica* Parkhaev, 2004, and *Yochelcionella crassa* Zhegallo in Esakova and Zhegallo, 1996. In South Australia, *Pojetaia runnegari* and species of *Anabarella* and *Pelagiella* occur in both the *M. etheridgei* and *D. odyssei* zones, but *Yochelcionella* sp., *Stenotheca drepanoida* and the bradoriid *L. sayutinae* are restricted to the latter zone (Figs. 5, 6, 10, 12, 13). Confident correlation with the Australian zones is problematic as both regions share mostly molluscan genera. However, occurrence of *L. sayutinae* suggests that the Bystraya Formation assemblage may be age-equivalent to that of the *D. odyssei* Zone in South Australia.

The bradoriid *Sinskolutella* was first described from the Botoman Sinsk Formation on the Siberian Platform (Melnikova, 1998). *Sinskolutella* also occurs with a diverse shelly fauna of early Botoman (*Bergeroniellus gurarii* Zone) age at the Achchagy-Tuoydakh locality, Yakutia, eastern Siberia (Ivantsov and Wrona, 2004). Recently, Betts et al. (2014) described *S. cuspidata* from South Australia where it is particularly abundant in the *M. etheridgei* Zone (Betts et al., 2016b, appendix 3), but ranges up from the *K. rostrata* Zone (Betts et al., 2016b, appendix 7). Shield fragments with the distinctive micropulvinate microornament of this species also occur in the *D. odyssei* Zone (Figs 7, 9). Thus, *Sinskolutella* has limited biostratigraphic utility, especially for intercontinental correlation (Figs 13, 21).

The macromollusc *Marocella mira* (Fig. 17D) has been documented from both Australia and an unnamed unit on the Anabar Anticline, Siberia ("Lenan Stage" of Vostokova, 1962, now Toyonian, Peng et al., 2012). In the Arrowie Basin, *M. mira* is restricted to the *D. odyssei* Zone in the MMF, ER9 and CR2 sections (Topper et al., 2009; Jacquet and Brock, 2015). However, *M. mira* has a very long stratigraphic range and is therefore unsuitable for high-resolution correlation.

5.2.4 Laurentia

Skovsted and Peel (2007) described a shelly fossil assemblage from the Forteau Formation in the Bonne Bay region of western Newfoundland, and noted the strong faunal connection between Laurentia and other regions such as East Gondwana (Australia and Antarctica), North China, Mongolia and Siberia. Taxa from the Forteau Formation include a number of genera and some species that are also found in South Australia, including *Cupitheca holocyclata* (Skovsted et al., 2016), *Eoobolus*, and *Pojetaia runnegari* (Bengtson et al., 1990). In the Arrowie Basin, *Eoobolus* has a long range from the upper *M. etheridgei* Zone through to the *D. odyssei* Zone. *Pojetaia runnegari* is most common in the *M. etheridgei* Zone, but does occur in the *D. odyssei* Zone in the MMF (Fig. 5), NB (Fig. 10) and PIN sections (Fig. 11), and *C. holocyclata* occurs in the AJX-M section, also ranging from the *M. etheridgei* Zone to the *D. odyssei* Zone (Skovsted et al., 2016). The Forteau Formation also contains *Lapworthella shodakensis*, *Mackinnonia* sp., *Pelagiella* sp., *Stenotheca* sp., *Yochelcionella americana* Runnegar and Pojeta, 1980, and *Yochelcionella* cf. *chinensis* (Skovsted and Peel, 2007, table 1). In the Arrowie Basin, *Pelagiella* and *Mackinnonia* range from the upper *M. etheridgei* Zone to the *D. odyssei* Zone (Betts et al., 2016b, fig. 18A-H, N-U), as does *Lapworthella fasciculata* (Betts et al., 2016b, fig. 21A-G). *Stenotheca drepanoida* is found in the MMF and NB sections (*D. odyssei* Zone) and *Stenotheca* steinkerns occur in the Yalkalpo-2 drill core (Fig. 17G-I, M). *Yochelcionella* sp. occurs in the Mernmerna Formation in the MMF and 10MS sections (*D. odyssei* Zone) (Fig. 17N). The occurrence of the trilobites *Olenellus* and *Bonnia* in the Forteau Formation indicate a Dyeran age (correlated with Series 2, Stages 3-4 by Peng et al. 2012, fig. 19.11), indicating that the Forteau Formation shelly fauna is more likely to be age-equivalent with the *D. odyssei* Zone in South Australia.

Broad correlation between South Australia and Laurentia is also made possible by the occurrence of *Mickwitzia* in both regions. In the Arrowie Basin and on the Stuart Shelf, occurrences of *Mickwitzia* are restricted to the *D. odyssei* Zone in sections AJX-M (also within the *P. tatei* trilobite Zone; Betts et al., 2016b, appendix 1) and MMF (= *P. bunyerooensis* trilobite Zone; Fig. 5), as well as the SCYW1-791A core (Fig. 2). *Mickwitzia muralensis* Walcott, 1913 occurs in the lower Cambrian Mural Formation in the southern Canadian Rocky Mountains, along with abundant trilobites, hyoliths, and linguliform and obolellid brachiopods (Balthasar, 2004). This unit covers both the *Nevadella* and *Bonnia-Olenellus* zones, which is broadly equivalent to the *P. tatei*, *P. bunyerooensis* and *P. janeae*

24

zones in Australia (Jell in Bengtson et al., 1990). *Mickwitzia occidens* Walcott, 1908 occurs in the Indian Springs Lagerstätte (Poleta Formation) in Nevada, which is of *Nevadella* Zone age (English and Babcock, 2010). Thus, these occurrences support tentative correlation of the *D. odyssei* Zone in South Australia with the *Nevadella* to *Bonnia-Olenellus* zones in Laurentia. Recovery of better preserved *Mickwitzia* specimens from South Australia would allow for accurate species identification and may permit more robust correlations in the future.

Landing and Bartowski (1996) documented an assemblage from the Browns Pond Formation in the Taconic allochthon in eastern New York that contains *Lapworthella shodakensis*, abundant echinoderm ossicles, hyoliths (including *Conotheca laurentiensis*) and diverse micromolluscs. The Browns Pond molluscs include *Fordilla troyensis, Helcionella subrugosa, Mackinnonia obliqua*, *Mackinnonia taconica*, *Pelagiella primaeva* and *Yochelcionella* sp. (Landing and Bartowski, 1996). The Browns Pond fauna also contains *Calodiscus lobatus* and *Elliptocephala asaphoides* and is assigned to the lower *Elliptocephala asaphoides* trilobite assemblage (= *Olenellus* Zone; Williams et al., 2015). The *Olenellus* zone correlates in part with the *P. janeae* Zone in South Australia (Fig. 21). These molluscan occurrences also support correlation of the *D. odyssei* and *Olenellus* zones, at least in part.

Skovsted (2004) described a mollusc assemblage from the Bastion Formation in Greenland that has similarities to the Browns Pond fauna (Landing and Bartowski, 1996). The Bastion Formation is broadly correlated with the Dyeran, based on the presence of trilobites typical of the *Bonnia–Olenellus* Zone (Skovsted, 2004). Many of the mollusc taxa are conspecific with those from South Australia, including *Anabarella australis* Runnegar in Bengtson et al., 1990*, Mackinnonia rostrata*, *Pelagiella subangulata*, and *Pojetaia runnegari*. Congeners of both regions include *Emargimantus* (Skovsted et al., 2012), *Stenotheca*, and *Xianfengella*, further supporting the connection between the *D. odyssei* Zone assemblages of South Australia and the Bastion Formation fauna of Greenland.

Other shelly fossils from the Bastion Formation were described by Malinky & Skovsted (2004), Skovsted et al. (2004), Skovsted (2006) and Skovsted and Holmer (2005). Close faunal similarities enabled Skovsted (2006) to correlate this assemblage with the South Australian *Bemella communis* and *Stenotheca drepanoida* zones of Gravestock et al. (2001). In addition to the molluscs mentioned above, other shelly taxa common to both regions

25

include the lingulid brachiopod *Eoobolus,* the lobopodian *Microdictyon*, species of the tommotiid *Lapworthella*, as well as a range of hyoliths such as *Conotheca australiensis* Bengtson in Bengtson et al., 1990, *Cupitheca holocyclata* (Bengtson in Bengtson et al., 1990)*, C. hemicyclata* (Bengtson in Bengtson et al., 1990)*, Hyptiotheca karraculum* Bengtson in Bengtson et al., 1990, *Microcornus eximius* Duan, 1984*, M. petilus, Parkula bounites* Bengtson in Bengtson et al., 1990*,* and species of *Triplicatella* (Skovsted et al., 2004). Many of the taxa common to both regions have ranges that, in South Australia, span both the *M. etheridgei* and *D. odyssei* zones (e.g., *Lapworthella, Mackinnonia, Microdictyon, Pelagiella, Pojetaia*).

Bradoriids from the Bastion Formation, such as *Albrunnicola* spp. (likely to include *A. bengtsoni*), *Liangshanella sayutinae* (Melnikova, 1988), and *Mongolitubulus henrikseni* (Skovsted and Peel, 2001; Skovsted, 2006) also occur in the *D. odyssei* Zone in South Australia (Fig. 13). However, while *A. bengtsoni* is mostly confined to the *D. odyssei* Zone, it does occur in the upper *M. etheridgei* Zone in the RC, ER9 and BALC sections (Fig. 13).

5.2.5   Avalonia

The Lower Comley Limestones Formation in Shropshire, England is reported to contain *Eccentrotheca kanesia*, *Lapworthella cornu*, *Lapworthella nigra* and *Pelagiella lorenzi* (Brasier, 1989). The presence of *E. kanesia* in this unit (horizon Ac$_2$ = *Callavia* Zone) represents the youngest occurrence of the genus and indicates a remarkably long range for the species. Sclerites ascribed to *E. kanesia* are reported to co-occur with *Watsonella crosbyi*— the latter suggested to be a key species in the definition of the base of Stage 2 [Peng et al., 2012]—in Member 4 of the Chapel Island Formation in Newfoundland (Placentian Series) (Landing et al., 1989). This suggests that either *E. kanesia* has an extremely long stratigraphic range, or the sclerites of *Eccentrotheca* from the Lower Comley Limestones Formation and the Chapel Island Formation belong to different taxa. In the Arrowie Basin, *Eccentrotheca helenia* is restricted to the *M. etheridgei* Zone, and so is older than the occurrence of *E. kanesia* from the Lower Comley Limestones Formation (Brasier, 1989). The enigmatic shelly fossil *Rhombocorniculum cancellatum* also occurs in the Comley Limestones Formation, from horizons Ac$_2$ to Ad (Brasier, 1989, fig. 5.7). This permits correlation of the *Callavia* Zone with the *Cambroclavus fangxianensis – Rhombocorniculum cancellatum* AZ in South

China, which, in turn, can be correlated with the *D. odyssei* Zone (as discussed in Section 5.2.1).

Avalonian successions in Newfoundland are difficult to correlate globally because many shelly taxa that have restricted stratigraphic ranges in other terranes have apparently much longer ranges in Avalonia (Landing, 1988). For example, *Watsonella crosbyi* has a 650 m composite range from the Chapel Island Formation to the Fosters Point Formation within the *Camenella baltica* Zone, just beneath the unconformity with the overlying Brigus Formation (*Callavia broeggeri* Zone = ~*P.bunyerooensis* Zone) (Landing and Benus, 1988; Landing et al., 2013; Landing and Kouchinsky, 2016). However, in all other lower Cambrian terranes, *W. crosbyi* occurs close the the base of Stage 2 (Jacquet et al., 2016).

Tentative correlation of the *Callavia* Zone in Newfoundland and the *D. odyssei* Zone in South Australia can be made using bradoriid and trilobite genera. The bradoriids *Beyrichona* and *Hipponicharion* have been reported from the Somerset Street Member of the Hanford Brook Formation (Westrop and Landing, 2000). In the Arrowie Basin, *Hipponicharion australis* and *Albrunnicola bengtsoni* (= *Beyrichona chinensis*, *sensu* Topper et al., 2011b) co-occur in the upper *D. odyssei* Zone (= *P. janeae* Zone) in the DBS section (Figs 4, 13; Topper et al. 2007). The eodiscoid trilobite *Serrodiscus* is reported from the St. Mary's and Jigging Cove members of the Brigus Formation, Avalon Peninsula, Newfoundland (Westrop and Landing, 2011). In South Australia, *Serrodiscus gravestocki* occurs in the *P. janeae* trilobite Zone (= upper *D. odyssei* Zone) in the Arrowie Basin (DBS section, Fig. 4; see also Jell in Bengtson et al., 1990; Paterson and Brock, 2007; Topper et al. 2007).

5.2.6   Baltica

The early Cambrian shelly fossil record in Scandinavia is sparse, probably due to a lack of suitable facies – shallow water siliciclastics dominate until the late early to middle Cambrian (Nielsen and Schovsbo, 2011). Pre-trilobitic faunas include *Mobergella*, *Volborthella*, 'Torellella' laevigata and *Platysolenites*, which are long-ranging and of limited use for correlation (Nielsen and Schovsbo, 2011); see also Ahlberg (1989) for similar fossils recovered from the lower Cambrian File Haidar Formation in Gotland. However, the presence of *Aldanella attleborensis* in the Lontova Formation of Estonia and a drill core in

27

southeastern Poland, allows correlation with the lower part of Cambrian Stage 2 (Isakar & Peel 2007; Parkhaev & Karlova 2011). Bergström and Ahlberg (1981) described a shelly fauna from the lower Cambrian Gislöv Formation in Scania, southern Sweden that includes the trilobites *Calodiscus lobatus* (Hall, 1847) and *Holmia sulcata* Bergstrom, 1973, probable helcionelloid molluscs, phosphatic brachiopods, the bradoriid *Indiana*? sp., and *Lapworthella cornu*, suggesting possible correlation with the *D. odyssei* Zone assemblages in the Arrowie Basin. This correlation is further corroborated by the presence of *Rhombocorniculum cancellatum* in the Gislöv Formation (CBS personal observation).

In the *Mickwitzia* Sandstone of south-central Sweden, *Mickwitzia monilifera* (Linnarsson, 1869) and *M. pretiosa* Walcott, 1908 (which are probably synonyms) co-occur with shelly fossils such as *Mobergerella* sp., *Volborthella tenuis* Schmidt, 1888 and *Torellella laevigata* (Linnarsson, 1873), in addition to a variety of ichnotaxa (Jensen, 1990; 1993). The *Mickwitzia* Sandstone has been placed in the *Schmidtiellus mickwitzi* or *Holmia inusitata* biozones (Jensen, 1990), which Zang et al. (2007) correlated with pre-trilobitic to *P. janeae* Zone strata in South Australia based on acritarchs. Occurrences of *Mickwitzia* in the Arrowie Basin are restricted to the *D. odyssei* Zone (AJX-M, Betts et al., 2016b, fig. 2; SCYW-791A, Fig. 2). However, fragmentary material precludes species assignment, thus direct correlation of the *Mickwitzia* Sandstone faunas with those of the *D. odyssei* Zone remains uncertain.

5.2.7 Antarctica

On the East Gondwanan margin, diverse assemblages of shelly fossils from the upper Shackleton Limestone in the Transantarctic Mountains can be easily correlated with those of the *D. odyssei* Zone in South Australia. *Dailyatia odyssei*, *D. braddocki* Evans and Rowell, 1990 and *Kennardia* spp. were recovered from the central Transantarctic Mountains (Evans and Rowell, 1990). Also, a recently recovered fauna from the Holyoake Range includes *D. odyssei, Cambroclavus absonus*, the linguliformean brachiopods *Eodicellomus elkaniiformis*, *Eohadrotreta* sp., *Eoobolus* spp., and *Karathele yorkensis*, and fragmentary remains of the spinose bradoriid *Spinospitella coronata* (Brock et al., 2012). Additional faunal elements include the helcionelloid molluscs *Figurina* sp., *Parailsanella* sp., *Pelagiella* sp.*, Pojetaia runnegari* Jell, 1980, *Obtusoconus* sp., and *Yochelcionella* sp., as well as abundant hyoliths, especially *Cupitheca holocyclata* Bengtson in Bengtson et al., 1990. This assemblage

28

provides direct correlation with the *D. odyssei* Zone faunas in the Arrowie Basin (particularly those from the MMF and 10MS sections).

This newly discovered assemblage from the Holyoake Range (Brock et al., 2012) is also remarkably similar to a fauna described from exotic limestone clasts within the Miocene Cape Melville Formation on King George Island, West Antarctica (Holmer et al., 1996; Wrona 2003, 2004, 2009). This fauna includes the tommotiids *D. odyssei* (= *D. ajax sensu* Wrona, 2004; synonymised by Skovsted et al. [2015a]), and *Kelanella* (= *L. fasciculata sensu* Wrona 2003, 2009; synonymised by Devaere et al. [2014]). Bradoriids such as *Albrunnicola bengtsoni*, *Liangshanella birkenmajeri* Wrona, 2009, and *Mongolitubulus squamifer* were also recovered from these erratics, in addition to a diverse molluscan assemblage, including *Anabarella* cf. *argus* Runnegar in Bengtson et al., 1990, *Beshtashella tortilis* Missarzhevsky in Missarzhevsky and Mambetov 1981, *Paraconus* cf. *staitorum* Runnegar in Bengtson et al., 1990, *Pelagiella madiensis* (Zhou and Xiao, 1984), and *Yochelcionella* sp., as well as abundant hyoliths and halkieriid sclerites (Wrona, 2009).

Wrona (2009) recognised the close similarity of the King George Island fauna to assemblages described from the Stansbury Basin (Gravestock et al., 2001), and suggested that its age was approximately equivalent to the *P. tatei* Zone (= lower *D. odyssei* Zone). However, based on the stratigraphic ranges of some conspecifics in the Arrowie Basin, for example, *Beshtashella tortilis* in the MMF and NB sections, it is likely that the age of the King George Island fauna extends into the *P. bunyerooensis* Zone portion of the *D. odyssei* Zone. Notwithstanding, it is important to note that the shelly fossils from the various erratic boulders of the Cape Melville Formation may represent a mix of assemblages from different biozones.

Evans (1992) reported the macromollusc *Marocella mira* from the Shackleton Limestone in the Transantarctic Mountains. *Marocella mira* occurs in the Mernmerna Formation and Oraparinna Shale (mid-upper *D. odyssei* Zone) in the Flinders Ranges (Skovsted et al., 2007; Topper et al., 2009; Jacquet and Brock, 2015). In the MMF section, *M. mira* has a range of 27.8 m through the *P. bunyerooensis* Zone (Fig. 5, Appendix 4; Topper et al., 2009). In the CR2 (Jacquet and Brock 2015, fig. 2) and ER9 (Fig. 3) sections, *M. mira* co-occurs with *P. janeae, Serrodiscus gravestocki* and *Atops rupertensis*, indicating a *P. janeae* Zone age.

5.2.8 West Gondwana

The Cambrian shelly fossil record of Morocco has rather limited faunal ties with South Australia. A notable exception includes *Marocella mira* from the upper Tatelt Formation (*Hupeolenus* Zone) and the Brèche à *Micmacca* Member (*Marocconus notabilis* Zone) in the Jbel Wawrmast Formation in the High Atlas Mountains (Geyer and Landing, 2006; Betts, personal observation). *Lapworthella vandali* Landing, Geyer and Heldmaier, 1995 was also recovered from the Brèche à *Micmacca* Member in the Jbel Wawrmast Formation (Landing et al., 1995). The age of these occurrences is likely to be closer to the Cambrian Series 2–3 boundary (see Landing et al., 2013), hence are younger than occurrences of *M. mira* and *Lapworthella fasciculata* in South Australia.

Shelly faunal connections between the lower Cambrian of Spain and South Australia are also sparse. Topper et al. (2009) noted that *Marocella morenensis* from the Sierra Morena in Spain (Marianian Stage; in part, equivalent to the Banian in Morocco, the Dyeran in Laurentia and the Botoman in Siberia; Liñán et al., 2015) (Yochelson and Gil Cid, 1984) may be a junior synonym of *M. mira*. Interestingly, the Spanish localities that have produced specimens of *M. morenensis* also host the trilobites *Alanisia guillermoi* and *Serrodiscus* cf. *S. speciosus* (Yochelson and Gil Cid, 1984). In South Australia, *A. guillermoi* is restricted to the *P. huoi* and *P. tatei* trilobites zones, whereas *Serrodiscus gravestocki* occurs only in the *P. janeae* trilobite Zone (Figs 3, 4; Jell in Bengtson et al., 1990). *Marocella* also occurs in the Marianian-Bilbilian Láncara Formation in north-west Spain with other molluscs including *Mackinnonia* cf. *rostrata*, *Pelagiella subangulata* and *Yochelcionella* (Liñán et al., 2004; Wotte, 2006). Other shelly fossils from this succession include *Hadimopanella oezgueli* (Liñán et al., 2004). In South Australia, *Mackinnonia* and *Pelagiella* range into the *D. odyssei* Zone from the *M. etheridgei* Zone, however *Yochelcionella* and *Hadimopanella* are restricted to the *D. odyssei* Zone (Figs. 4-6). These trilobite, mollusc and other shelly fossil occurrences, coupled with the known stratigraphic range of *M. mira* from the Arrowie Basin (discussed above), provides a tentative and relatively broad correlation of part of the Marianian Stage with the *D. odyssei* Zone in South Australia.

Cambrian shelly faunas containing tommotiids (e.g., *Kelanella*), brachiopods (e.g., *Eoobolus*), trilobites (e.g., *Serrodiscus*), bradoriids, and a variety of micromolluscs (including *Pelagiella subangulata* and *Pojetaia runnegari*) have also been documented from the southern Montagne Noire in France (Devaere et al., 2014) and the Görlitz Syncline of eastern

Germany (Elicki, 1994, 1996, 2007). However, similarities with South Australian assemblages from the *D. odyssei* Zone are largely at the generic level, thus making correlation difficult.

6. CONCLUSION

This study emphasises the importance of detailed stratigraphic sampling and rigorous taxonomic work to underpin a robust and repeatable biostratigraphy. Extensive recent palaeobiological and systematic investigations into early Cambrian shelly fossils from South Australia have laid the foundation for introducing the new biostratigraphic scheme (Brock and Paterson, 2004; Skovsted et al., 2006, 2008, 2009a,b,c, 2011a,b, 2014, 2015a, b, 2016; Topper et al., 2007, 2009, 2010, 2011a, b, 2013a; Larsson et al., 2014; Betts et al., 2014, 2016a). Herein, we add to the known diversity of shelly taxa from the Arrowie Basin and describe the oldest known acrotretoid brachiopod from Australia, *Eohadrotreta* sp. cf. *E. zhenbaensis*, which is also the first record of the genus in Australia. Four new bradoriid species and three new genera are documented: *Acutobalteus sinuosus* gen. et sp. nov., *Eozhexiella adnyamathanha* gen. et sp. nov., *Manawarra jonesi* gen. et sp. nov., and *Mongolitubulus decensus* sp. nov.

Stratigraphic ranges of key tommotiids, brachiopods, molluscs, arthropods and problematic forms have been determined from across the Arrowie Basin and have enabled development of three well-resolved shelly fossil biozones that span the Terreneuvian, Stage 2 to Series 2, Stages 3–4: the *Kulparina rostrata*, *Micrina etheridgei* and *Dailyatia odyssei* zones (Betts et al. 2016b,c; herein). These shelly fossil zones allow robust correlation of strata across the Arrowie Basin and with strata in neighbouring basins such as the Stansbury, Georgina, Officer and Amadeus basins. In addition, despite significant provincialism of faunas, global correlation of the succession in the Arrowie Basin is now dramatically improved. Terranes such as Avalonia and Baltica have a sporadic early Cambrian fossil record, which limits opportunities for correlation. Correlations with these and other regions (e.g., Siberia) are based mostly on genera, and thus must be reinforced with additional fossil data or other temporal proxies (e.g. isotope chemostratigraphy). However more robust, species-level correlation is possible between lower Cambrian strata in South Australia and successions in North and South China, Antarctica, West Gondwana and Laurentia.

This study (in conjunction with Betts et al., 2016b) represents the first broad-scale, temporally controlled, biostratigraphic analysis of early Cambrian shelly fauna from the Arrowie Basin, South Australia. Synthesised data from a total of 21 measured stratigraphic sections and drill cores (Betts et al. 2016b and herein) illustrate the vast wealth of information preserved in the lower Cambrian successions in the Arrowie Basin. The biostratigraphic scheme demonstrates unequivocally the correlative value of early Cambrian shelly faunas, and provides a reliable means of correlating South Australian lower Cambrian successions for the first time.

7.   SYSTEMATIC PALAEONTOLOGY

Figured specimens have been allocated SAM P numbers and are housed in the South Australian Museum (palaeontological collections). *Eohadrotreta* sp. cf. *E. zhenbaensis* is described by GAB and all bradoriids are described by MJB, except for *Acutobalteus sinuosus* gen. et sp. nov. and *Liangshanella sayutinae*, which are described by SMJ and MJB.

Phylum BRACHIOPODA (Duméril, 1806)

Order ACROTRETIDA Kuhn, 1949

Superfamily ACROTRETOIDEA Schuchert, 1893

Family ACROTRETIDAE Schuchert, 1893

Eohadrotreta Li and Holmer, 2004

Type species. Eohadrotreta zhenbaensis Li and Holmer, 2004, p. 204 from the lower Shuijingtuo Formation, Qiongzhusian Stage, Xiaoyang section, South Shaanxi, China.

Other species included. Eohadrotreta zhuijiahensis Li and Holmer 2004, p. 208, fig. 14A-O, from the Guojiaba Formation, Fucheng section southern Shaanxi, PR China. *Eohadrotreta* sp. cf. *E. zhenbaensis* from the upper Mernmerna Formation, 10MS section, central Flinders Ranges, South Australia.

Diagnosis. See Li and Holmer, (2004, p. 204).

Discussion. The taxon recovered from South Australia shares very similar dimensions, external ornament and other gross morphological features of *Eohadrotreta* Li and Holmer (2004) from the Lower Cambrian of Shaanxi Province in China. However, the presence of apical pits in the ventral valve and a poorly developed median septum that does not appear to extend beyond 50% valve length in the Australian taxon differs slightly from the concept of *Eohadrotreta* as outlined by Li and Holmer (2004). In addition, no specimens in the Australian collections display the open, unrestricted notch-like foramen characteristic of juvenile specimens of *E. zhenbaensis*, though the foramen has a very similar shape, cuts the posterior portion of the larval shell to the same extent and has a similarly shallow intertrough (compare fig 15A-D, H with Li and Holmer 2004, fig. 12A-D, F-G).

***Eohadrotreta* sp. cf. *E. zhenbaensis* Li and Holmer, 2004 (Fig. 15A-O)**

Material. 20 dorsal valves and 12 ventral valves from 10MS/515.0, 10MS/541.0, 10MS/547.3, 10MS/551.5, 10MS/571.2 in the upper Mernmerna Formation and Oraparinna Shale, ranging from 476.3 to 526.8 m true thickness above the base of the section.

Description. Shell weakly ventribiconvex, subcircular to slightly transversely ovoid in outline. Larval shell poorly preserved in most specimens, averaging 0.18 mm in width with tiny non-overlapping, concave, circular pits about 1-2 µm across. External ornament of shell with well-developed, closely packed concentric growth filae giving a wrinkled effect to the surface of larger specimens. In mature specimens the concentric ornament becomes more imbricated with step-like concentric lamellae developed towards shell margin. Ventral valve 79% as long as wide (n = 5); maximum width near midvalve. Ventral valve low, broadly conical with steeply to moderately procline pseudointerarea hosting a broad, shallow intertrough. Pedicle foramen elongately oval to pyriform in shape, not enclosed within larval shell; foramen with average width 0.08 mm, length 0.10 mm. Ventral valve interior with a pair of small, shallow apical pits; apical process lacking.

Dorsal valve gently convex, on average 85% as long as wide. Pseudointerarea short, orthocline, occupying 40% of shell width. Median groove broad, shallow, well defined with distinct flexure lines, occupying on average 80% of pseudointerarea width. Dorsal median buttress well developed, originating directly below median groove and extending anteriorly to approximately 45-55% shell width as a very low median ridge; the anterior half of the ridge is

33

often little more than a low swelling. Cardinal muscle scars large, elongately ovoid, extending 30-35% shell length.

Shell structure. Shell structure is typical acrotretid columnar structure (Fig. 15O).

Discussion. Eohadrotreta zhenbaensis occurs with an endemic assemblage of phosphatic linguifornean taxa including *Palaeobolus liantuoensis* Wang, *Lingulellotreta malongensis* (Rong), and *Botsfordia minuta* sp. nov. from the lower member of the Shuijingtuo Formation, Xiaoyang section, Shaanxi Province. Disconformably underlying this package in the Xiaoyang section is the Xihaoping Member which includes *Eoobolus* aff. *viridis* (Cobbold), *Eoobolus*? *shaanxiensis*, and *Kyrshabaktella*? sp., along with sponge spicules, molluscs, cambroclaves and hyolithelminths. A similar fauna derived from the Mernmerna Formation and Andamooka Limestone in South Australia was referred to as the "*Eoobolus* aff. *viridus* assemblage" by Jago et al. (2006) and included abundant *Kyrshabaktella davidi* with *Eoobolus* aff. *viridis* and *Minlatonia tuckeri* along with tommotiids and cambroclaves. This association is typical of the *D. odyssei* Zone fauna. This taxon represents the oldest acrotretid recovered from the lower Cambrian succession of South Australia.

In erecting *Eohadrotreta*, Li and Holmer (2004) described two species: *E. zhenbaensis* (type species) from the lower Shuijingtuo Formation in the Xiaoyang section and *E. zhujiahensis* from the upper Guojiaba and basal Xiannudong formations from the Fucheng section, south Shaanxi, China. Both taxa are very similar in overall dimensions and shape, but *E. zhujiahensis* is distinguished by having a closed foramen at later ontogenetic stages, a lower conical ventral valve, and vestigial intertrough. It is possible that such minor differences could be within the range of normal intraspecific variation and if so, these taxa may prove to be synonymous.

Eohadrotreta sp. cf. *E. zhenbaensis* from the Mernmerna Formation in the 10MS section is very similar in size, shape and ornament to the type species, *E. zhenbaensis*. The type species is described as "lacking a well-defined apical process and pits" (Li and Holmer 2004, p. 207) and whilst *Eohadrotreta* sp. cf. *E. zhenbaensis* from South Australia lacks an apical process, it does possess a pair of shallow apical pits (Fig. 15B) (often filled and obscured by sedimentary material).

The original diagnosis of *E. zhenbaensis* reports that the dorsal medium septum is "low" (Li and Holmer 2004, p. 204), but the corresponding description of the type species

indicates that the dorsal medium septum is "distinct" (Li and Holmer 2004, p. 207). In addition, the median septum of *Eohadrotreta* (based on *E. zhenbaensis*) is described as "well developed" by Holmer and Popov (2007). The Chinese and Australian taxa have a well-developed median buttress (see dorsal valve interiors of *E. zhenbaensis* Li and Holmer 2004, fig. 11I-L and *E.* sp. cf. *E. zhenbaensis* from South Australia (Fig. 15E-F,I, K-L). In both species, the anterior half of the median ridge becomes little more than a low swelling, often only perceptible in oblique view. The median ridge in the Chinese species does appear to extend a little further beyond mid-valve than in the Australian species, but this is unlikely to be a taxonomically significant feature.

There are very strong morphological similarities between the Australian taxon and the Chinese type species, with the only apparent difference being the presence of shallow apical pits in the Australian material. Whilst apical pits are clearly absent in the juvenile specimen of *E. zhenbaensis* illustrated by Li and Holmer (2004, fig. 12A-B), no interiors of mature ventral valves are illustrated, making direct comparison with the mature Australian shells difficult.

Distribution. *Dailyatia odyssei* Zone; *P. janeae* trilobite Zone, upper Mermmerna Formation (10MS section), Bunkers Graben, Flinders Ranges, South Australia.

Phylum EUARTHROPODA Lankester, 1904 (see Ortega-Hernández, 2014)
Order BRADORIIDA Raymond, 1935
Family ?COMPTALUTIDAE Öpik, 1968

Manawarra **gen. nov.**

Type species. Manawarra jonesi gen. et sp. nov.

Diagnosis. Shields up to 3.5 mm in length with a straight or slightly curved dorsal fold. Shields weakly to strongly postplete with pronounced V-shaped anterior sulcus. Circular to sub-circular anterior node sometimes present. Well-developed border, rounded or flat with smooth margin. Shields bear circular pits that do not penetrate carapace. Pits absent on anterior sulcus.

Etymology. From the Adnyamathanha Aboriginal language. *Manawarra* = native plum, in reference to the very round, inflated shields.

Discussion. *Manawarra* gen. nov. from South Australia displays a suite of features characteristic of the Comptalutidae, such as a well-defined hinge line, a strong sulcus, continuous lateroadmarginal ridge, and strongly inflated shields with pitted ornament. However, the large size of these shields (up to ~3.5 mm) places them outside the maximum size range of comptalutids (2-2.5 mm long) (Hou et al., 2002). Hence, *Manawarra* gen. nov. is only tentatively assigned to this family.

   Manawarra gen. nov. exhibits a well-developed anterior sulcus and pitted shields that are also apparent in *Euzepaera hunanensis* Shu, 1990 (Shu, 1990, fig. 20). However, specimens of the latter are small (length under 1 mm), while the specimens from the Arrowie Basin attain ~3.5 mm in length. In addition, the Chinese material is not as strongly postplete as the specimens from South Australia. These differences may be ontogenetic, but *E. hunanensis* is Furongian in age and therefore unlikely to be related to *Manawarra jonesi* gen. et sp. nov.

Manawarra jonesi **gen. et sp. nov** (Fig. 18A-K)

?2006 *Euzepaera* sp.; Skovsted et al., p. 32, fig. 12C-H, non fig. 12A, B.

2007 *Euzepaera* sp.; Topper *et al.*, p. 90, fig. 12A-H.

2011 *Euzepaera* sp.; Topper *et al.*, fig. 7M.

Holotype. Right shield SAM P53697 from NB/58.75, (Fig. 18J).

Paratypes. Damaged right shield SAM P53692 from NB/66.6, (Fig. 18D, I) and conjoined specimen from NB/29.0, SAM P53691, (Fig. 18C).

Type locality and horizon. Mernmerna Formation, NB section, Mt. Chambers area, eastern Flinders Ranges (Fig. 1), horizon NB/58.75, located 41.7 m above the base of the section (Fig. 10).

Diagnosis. Shields large, dorsal fold straight or slightly curved in median part. Cardinal corners taper to points. Postplete with inflated shields. Anterior V-shaped sulcus well-developed. Except for anterior sulcus, surface of shield covered by circular pits up to 29 µm

36

in diameter. Pits do not penetrate shell. Shield with wide border and smooth margin. Small spine on posterodorsal margin.

Etymology. In recognition of Dr Peter Jones, for his contributions to study of Australian bradoriids and ostracods.

Description. Large (up to 3.5 mm in length and 2.6 mm in height) inflated, postplete shields. Prominent V-shaped anterior sulcus gives a very rounded shape to the "body" of the shield (Fig. 18A-C, F, G, I-K). Dorsal fold is usually straight, sometimes with a slight cusp. Cardinal corners taper to points. Anterior cardinal spine joins convex anteroventral margin, and posterior cardinal spine joins concave posterodorsal margin. Ventral margin and posteroventral margin rounded. Short spine is present on posterodorsal margin (Fig. 18G). Wide border (~200 µm width) with a smooth margin that connects anterior and posterior cardinal corners. External ornament consists of circular pits (up to 29 µm in diameter) (Fig. 18D). Pits do not completely penetrate shield and do not occur on the anterior sulcus. Internally, bottom of pits covered by domed "phosphatic pads" (Topper et al. 2007, p. 90, (fig. 18H).

Material. 289 isolated shields, in addition to two articulated specimens, and an abundance of fragmentary material. Stratigraphic range extends from the *M. etheridgei* Zone (ER9, BHG, RC sections) to the *D. odyssei* Zone (MMF, DBS, BHG, RC, 10MS, NB and PIN sections). In the DBS section, *M. jonesi* gen. et sp. nov. occurs with trilobites indicative of the *P. janeae* Zone. See Table 1 for specimen counts.

Discussion. The fragmentary nature of previously illustrated material by Skovsted et al. (2006) and Topper et al. (2007, 2011b) precluded definitive taxonomic identification of *M. jonesi* gen. et sp. nov. Additional material available for the present study is also often fragmentary due to the fragile nature of the large shields. However, the large number of specimens recovered from seven separate stratigraphic sections now allows a full description of the taxon.

Many bradoriid species exhibit pitted ornament. However, pits in *M. jonesi* gen. et sp. nov. are different to those in *Bradoria scrutator* (Matthew, 1899), for example, where they are only visible after the diagnostic, concentrically striated external ornament is sloughed

37

away (Siveter and Williams, 1997, pl. 1, figs 1-14). Analysis of over 280 acid-processed specimens from the Arrowie Basin has not revealed additional carapace layers covering the pits in *M. jonesi* gen. et sp. nov. and thus is likely to be the true exterior texture of the shields.

Siveter and Williams (1997, pl. 2, fig. 3) described a bradoriid from the Hanford Brook Formation in New Brunswick with pits covering an inflated shield and assigned it to *Bradoria*? *oculata* (Matthew, 1895). The specimen is incomplete, but shows a straight dorsal fold and a small spine at the posterodorsal margin. It also seems to show a smooth anterior sulcus, similar to that in *M. jonesi* gen. et sp. nov. *Bradoria*? *oculata* was described as bearing a small anterodorsal node, although this may be an artefact resulting from the style of preservation and method of recovery (crack-out). In addition, the size of this specimen (~3.5 mm length) is similar to that of *M. jonesi* gen. et sp. nov. Siveter and Williams (1997) noted that this specimen is from strata of *Protolenus* Zone (= Botoman) age in New Brunswick (older than occurrences of *Bradoria scrutator*). *Manawarra jonesi* gen. et sp. nov. occurs with *P. janeae* Zone trilobites (DBS section) and is approximately the same age as *B.*? *oculata* from New Brunswick; however, different styles of preservation and the limited number of specimens from New Brunswick makes further comparison difficult.

Topper et al. (2007) included "sub-triangular" within the range of possible shield outlines of *Euzepaera* sp. (= *M. jonesi* gen. et sp. nov. herein) in the DBS section; however, this was the result of incorrectly extrapolating shape from fragmentary material. In addition, the specimen of *Euzepaera* sp. illustrated by Skovsted et al. (2006, fig. 12A, MMF section) has a complete ventral margin (dorsal fold not preserved), which is distinctly angular. While the margin is smooth, the border is narrow and exhibits a weak anterior lobe (also seen in Skovsted et al., 2006, fig. 12B). Hence, these specimens do not fit into the concept of *M. jonesi* gen. et sp. nov. However, fragments with pits, strong sulcus, internal phosphatic pads, and a straight dorsal margin (Skovsted et al., 2006, fig. 12C-H) indicate that *M. jonesi* gen. et sp. nov. possibly occurs in the MMF section. Better material needs to be recovered before this can be ascertained.

Distribution. *Micrina etheridgei* to *D. odyssei* zones; *Parabadiella huoi* to *Pararaia janeae* trilobite zones. South Australia: Arrowie Basin, Flinders Ranges (Ajax and Wirrapowie Limestones, Mernmerna Formation).

Eozhexiella **gen. nov.**

38

Type species. *Eozhexiella adnyamathanha* gen. et sp. nov.

Diagnosis. Small laminated shields (under 1 mm) with straight dorsal fold. Circular pits (~5-10 μm diameter) do not penetrate shields, and cover entire shield except for border or anterior node. Border up to ~50 μm wide with smooth margin. Weakly to strongly postplete. Anterior node variably developed.

Etymology. *Eo* = early, and *Zhexiella* = similar-looking genus from the early Ordovician of the Zhejiang Province, South China (Shu, 1990, p. 44).

Discussion. Eozhexiella gen. nov. from the Arrowie Basin has a similar pitted ornament to *Manawarra* gen. nov., but is much smaller and only weakly postplete (rather than clearly postplete), and does not have a prominent V-shaped anterior sulcus. *Eozhexiella* gen. nov. is similar to *Zhexiella* described by Shu (1990) from the early Ordovician of Zhejiang, South China, which is also a small, amplete to weakly postplete bradoriid bearing pits over the shields. Shu (1990, p. 44) described the free margin of *Zhexiella* as without a border; however, the figured material, whilst poorly preserved, shows evidence for a shallow furrow inside the margin (Shu, 1990, pl. 4, figs 1a, 2).

Shu (1990) also noted that the pits in the shield of *Zhexiella* have an inverted conical shape, which is not the case in the South Australian material. In addition, Shu (1990) counted four layers in the carapace wall, which are not apparent in the specimens from South Australia. Transverse sectioning through the shields showed that they are only composed of two layers (Betts et al., 2016a, fig. 5). Sectioning also showed that the pits do not penetrate the shield and so are unlikely to be "capillary pores" as suggested by Shu (1990). In addition, *Zhexiella* is from the Lower Ordovician Yinzhubu Formation (Tremadocian), and is much younger than the specimens from South Australia (Cambrian Series 2, Stages 3-4). Hence, they are unlikely to be closely related, and specimens from the Arrowie Basin are referred to *Eozhexiella* gen. nov.

Bradoria duyunensis Zhang, 2007 from the mid-Cambrian Gaotai Formation of Guizhou has an inflated shield and pitted ornament like species of *Euzepaera* (Zhang, 2007, pl. 20, fig. 4-9), as well as *Manawarra jonesi* gen. nov., but an anterior sulcus is only very weakly developed in one specimen of *B. duyunensis* (Zhang, 2007, pl. 20, fig. 6), and is not readily apparent in other figured material. The pitting in *B. duyenensis* appears to cover the

majority of the shield, similar to that in *Eozhexiella adnyamathanha* gen. et sp. nov. The holotype of *Bradoria duyunensis* is only 1.57 mm long, which is much shorter than the maximum length cited for other members of the Bradoriidae (6–7 mm) (Siveter and Williams, 1997), but is larger than *Eozhexiella adnyamathanha* gen. et sp. nov. (which is <1 mm in length). *Bradoria duyunensis* is also distinctly amplete with a sub-triangular outline, rather than weakly postplete and rounded like in *Eozhexiella adnyamathanha* gen. et sp. nov. Additionally, the anterior lobation in *B. duyunensis* is unclear. This is normally a diagnostic feature of *Bradoria*, suggesting that *B. duyunensis* may not be readily accommodated in this genus, nor *Eozhexiella* gen. nov. (based on the differences mentioned above).

Melnikova (2003) described *Euzepaera foveata* Melnikova, 2003 from the middle and upper Cambrian of Kazakhstan. The illustrated specimens feature the distinctive pitting seen in other species of *Euzepaera*, as well as *Eozhexiella* and *Zhexiella* (Melnikova, 2003, pl. 11, figs. 1-3). However, *E. foveata* does not bear the distinctive, smooth, V-shaped sulcus characteristic of other *Euzepaera* species. One specimen figured by Melnikova (2003, pl. 11, fig. 1) has a structure that could be interpreted as an anterior sulcus, but this appears to be pitted and it is probably the result of damage to the shield, rather than representing a true morphological feature. Specimens of *E. foveata* from Kazakhstan do feature important characteristics also seen in *Eozhexiella* and *Zhexiella*, such as a 'lip-like' border and smooth margin, a pitted carapace, obtuse angles at the cardinal corners, and a very round outline.

***Eozhexiella adnyamathanha* gen. et sp. nov.** (Fig. 18L-W)
2016a *Euzepaera* sp.; Betts et al., figs. 2A-K, 3A-H.

Holotype. Conjoined specimen SAM P53272 from MOG/667.4, (Fig. 18Q).

Paratypes. Conjoined specimens SAM P53271 and SAM P53703 from MOG/667.4 (Fig. 18P, U).

Type locality and horizon. Mernmerna Formation, MOG section, Flinders Ranges (Fig. 1), horizon MOG/667.4, located 393.4 m above the base of the section (Betts et al., 2016b, appendix 4).

Diagnosis. Small bradoriids with straight dorsal fold. Weakly amplete to postplete. Smooth, slightly rounded border entire between cardinal corners. Margin smooth. Well-developed duplicature. Pits (~5-10 µm diameter) cover shields except border. Pits do not penetrate carapace. Weak anterior node present or absent.

Etymology. To honour the indigenous Adnyamathanha People of the Flinders Ranges. *Adnyamathanha* translated means "hills or rock people". Pronounced "Uhdt-na-mut-na".

Description. Small bradoriids (length ~700 µm, height ~500 µm) with a straight dorsal fold. Weakly (almost amplete) to strongly postplete in outline. Obtuse angles at both cardinal corners. Anterior cardinal corner weakly obtuse, joining rounded anteroventral margin. Obtuse angle at posterior cardinal corner joins rounded posterodorsal margin. Ventral margin and posteroventral margin rounded. Border smooth (~50 µm wide). Duplicature well-developed (Betts et al., 2016a, fig. 3C). Pits ~5−10 mm diameter occur over shield, except on border, and do not penetrate shield (Betts et al. 2016a, figs 2G, 3D, F). A round node is variably developed at the anterior of the shield. If present, node does not bear pits (Fig. 18L-O, V-W).

Material. 13 specimens (eight conjoined and five separate shields) from the Mernmerna Formation (*D. odyssei* Zone), Flinders Ranges, South Australia (Fig. 18L-W, SAM P51224, SAMP53271-53274, SAM P53699-53703).

Discussion. Most specimens of *E. adnyamathanha* from the Arrowie Basin are well-preserved with conjoined shields closed, or with a ventral gape of up to 90^0. Many specimens from the MOG section remain conjoined despite sustaining damage to the shields, which are often bent and dented (Fig. 19U, V). Morphologically, *E. adnyamathanha* gen. et sp. nov. is very similar to the early Ordovician *Zhexiella venusta* Shu, 1990 from South China (many specimens of which are also preserved with conjoined shields closed). However, important differences in shield structure and pit morphology (discussed above), in addition to their very disparate stratigraphic ranges, indicate that the South Australian specimens are better placed in a separate genus.

Four specimens from the Arrowie Basin feature a circular anterior node (~100 µm diameter) (Fig. 18L-O). This node is weakly developed, and is delineated most clearly by the absence of circular surface pits (Fig. 18W). These specimens display all of the morphological

features that are otherwise characteristic of *E. adnyamathanha* gen. et sp. nov., which typically lack anterior nodes. As these four specimens are similar in size to other examples of *E. adnyamathanha* gen. et sp. nov., it is unlikely to be an ontogenetic feature of this taxon. It is possible that the anterior node is a sexually dimorphic character, but its function remains an open question.

A similar taxon from the Arrowie Basin, assigned herein as *Eozhexiella* sp. (Fig. 20O-R), features pitted ornament across the shield. The available material is fragmentary, but these specimens seem to have a smooth border and margin, and lack an anterior sulcus. The pitted ornament differs from that in *Manawarra jonesi* gen. et sp. nov. and *Eozhexiella adnyamathanha* gen. et sp. nov. Pits appear shallow (though most material is abraded), and bear a short, rounded protuberance at the base. Only six specimens with these features have been recovered (mostly from CR1 section, and one specimen from MOG; Betts et al., 2016b), and none are sufficiently well preserved to make a confident taxonomic assignment. Their occurrence is stratigraphically quite low (confined to the *M. etheridgei* Zone), and they may become an important correlation tool if better preserved specimens can be recovered.

Distribution. Dailyatia odyssei Zone (early Cambrian Series 2, Stage 3), Mernmerna Formation, Bunkers Graben, Arrowie Syncline and Mt. Chambers region in the Flinders Ranges, South Australia

Family HIPPONICHARIONIDAE Sylvester-Bradley, 1961

Acutobalteus gen. nov.

Type species. *Acutobalteus sinuosus* gen. et sp. nov.

Diagnosis. Valves small, subamplete and laterally compressed. Well defined straight dorsal fold; lacking lateroadmarginal ridge. Sharp-edged, thin confluent anterior and posterior lobes with highest relief near dorsal margin and distinctly sinuous S-shaped bend in posterior lobe. Small spine present behind posterior lobe, adjacent to posterodorsal curve of valve margin. Outer surface covered by pustulose ornament.

Etymology. Derived from the Latin *acuto* = sharp, and *balteus* = belt. In reference to the sharp-edged confluent lobation on the shield.

Discussion. *Acutobalteus sinuosus* gen. et sp. nov. displays diagnostic characteristics of the Hipponicharionidae Sylvester-Bradley, 1961, such as a subamplete outline and confluent lobation on the shields, but is unlike any of the established genera. It can be distinguished from other hipponicharionids by the presence of a characteristic S-shaped posterior lobe. Furthermore, most hipponicharionids exhibit at least one distinct central lobe, which may be present as a slight swelling, but this feature is not present in *Acutobalteus sinuosus.*

Acutobalteus sinuosus **gen. et sp. nov.** (Fig. 19A-G)

Holotype. Conjoined specimen SAM P 53704 from NB/67.3, (Fig. 19A).

Paratypes. Left shields SAMP 53705 and 53706 from NB/66.6 (Fig. 19B-C).

Type locality and horizon. Mernmerna Formation, NB section, Mt. Chambers area, eastern Flinders Ranges (Fig. 1), horizon NB/66.6, located 47.04 m above the base of the section (Fig. 10).

Diagnosis. As for genus.

Etymology. Latin, *sinuosus* = bent or curved. In reference to the characteristic S-shape of the posterior lobe.

Description. Carapace compressed, small, maximum length ~900 µm and height ~700 µm. Subamplete with subtriangular outline in lateral view, straight dorsal fold. Anterior cardinal corner obtuse and anteroventral margin gently curved. Posterodorsal margin straight, slightly convex or concave, posteroventral margin rounded. Small rounded node at posterodorsal margin. Anterior and posterior lobes are narrow but well-developed and form a confluent ridge (average of 143.5 µm between lobe and valve margin). Anterior lobe is parallel with the valve margin and forms a sharp ridge with high relief, which gradually becomes less prominent ventrally. Ridge follows shield margin and becomes U-shaped ventrally, merging with the base of the posterior lobe at the most convex part of the posteroventral margin. Posterior lobe forms a sharp and narrow S-shaped ridge with higher relief than the anterior lobe. Shield surface between lobes mostly flat, with microornament consisting of closely spaced pustules. Larger pustules occur between the carapace margin and confluent lobation, and smaller pustules occur on central parts of the shields. Both anterior and posterior lobes are ornamented with larger, regularly spaced pustules along apex of ridge (Fig. 19G).

Material. Total of 12 specimens; two conjoined and six separate shields from NB/66.6, three conjoined specimens form NB/67.3, and a single shield from 10MS/130.0. All Mernmerna Formation (*D. odyssei* Zone).

Discussion. Numerous hipponicharionid taxa display confluent anterior and posterior lobes, but *Acutobalteus sinuosus* gen. et sp. nov. is unique in possessing sharp, narrow, confluent ridges and a conspicuous S-shaped bend in the posterior lobe (Fig. 19A-D). *Acutobalteus sinuosus* gen. et sp. nov. bears some resemblance to *Bicarinella evansi* from lower Cambrian strata in the Schneider Hills, Antarctica (Rode et al., 2003, figs 2, 3). *Bicarinella evansi* has anterior and posterior lobes that form sharp, narrow ridges, and the posterior lobe shows very slight, sinuous flexure in some specimens. However, the carapace of the Antarctic species is more convex and lacks the confluent lobation present in *A. sinuosus*. Other bradoriids, including *Albrunnicola bengtsoni* Hinz-Schallreuter, 1993 from Antarctica (Wrona 2009) and *A. bengtsoni*, *Hipponicharion australis* and *Neokunmingella moroensis* from South Australia are similar to *Acutobalteus sinuosus* gen. et sp. nov. in that they have very compressed carapaces. However, lobation in these species is not confluent and so can be distinguished easily from the new taxon.

Distribution. Mernmerna Formation (*D. odyssei* Zone). In the 10MS section, a single specimen occurs relatively low in the *D. odyssei* Zone (Linns Springs Member, probable *P. tatei* trilobite Zone). In the NB section, material is likely to occur within the *P. bunyerooensis* - *P. janeae* zones (based on a similar bradoriid assemblage to that in DBS) (Fig. 13).

Family SVEALUTIDAE Öpik, 1968

Liangshanella Huo, 1956

Type species. *Liangshanella liangshanensis* Huo, 1956.

Diagnosis. See Zhang (2007, p. 138).

Discussion. Specimens from the NB section display a distinct marginal rim that is separated from the valve wall by a narrow furrow (Fig. 20B, D), which is a diagnostic feature of the Svealutidae Öpik, 1968. The Bradoriidae Matthew, 1902 are morphologically similar to the

Svealutidae, but lack a furrow inside the margin and are usually larger (up to 7 mm in length) (Siveter and Williams 1997; Zhang 2007). The specimens from the NB section reach a maximum length of 1.44 mm and are therefore closer to the smaller size range of svealutids (2–10 mm) (Williams et al., 2007; Zhang 2007).

Liangshanella sayutinae (Melnikova, 1988) (Fig. 20A-H)

1988 *Bradoria sayutinae;* Melnikova, p. 114, fig. 1a-d.
1997 *Liangshanella*? *sayutinae* (Melnikova); Melnikova et al., pl. 2, fig. 7.
2006 *Liangshanella sayutinae* (Melnikova); Skovsted, p. 1095, figs. 6.4-6.6, 7.8-7.10.

Diagnosis. Ovate shields postplete with straight dorsal fold. Shields convex with continuous border around smooth free margin. Anterior and posterior cardinal corners oblique. Anteroventral margin curved, ventral margin straight or weakly curved. Posterodorsal margin straight or with weak curve, maximum convexity posteroventral margin. Shield exterior smooth, or with faint wrinkles. Small spine at posterodorsal margin variously developed.

Description. Lateral outline ovate, moderately postplete, maximum length 1443 μm and height 1225 μm, with a straight hinge line and strongly inflated carapace. Obtuse angle at both cardinal corners. Smooth curve from anterodorsal margin to posterodorsal margin. External surface smooth, although some specimens display wrinkle patterns or cancellate ridges. One specimen displays a weak, reticulate ornament on the flat portion of the border (Fig. 20D). Border demarcated by a continuous shallow furrow is widest at anteroventral and posterodorsal margins. The extravagant "duplicature-like" structure on the interior of a single specimen (Fig. 20C, H) exhibits the network of wrinkles as seen on the exterior borders of other specimens (Fig. 20D) and is hence more likely to be remains of the second valve still attached along the free margin. Internal valve surface covered in regularly distributed shallow sub-circular depressions (Fig. 20H).

Material. 42 valves and an abundance of fragmentary material recovered from the NB section. Stratigraphic range extends from NB/1.0 (0.85 m above the base of the section) to NB/177.1 (147.8 m above the base) in the upper Mernmerna Formation (*D. odyssei* Zone).

Discussion. The NB section material bears close morphological similarity to specimens assigned to *L. sayutinae* by Skovsted (2006, fig. 6.4-6.6, 6.8 - 6.10) from the lower Cambrian Bastion Formation. The specimens from Greenland display a straight dorsal fold, postplete outline, well-developed border and smooth shield with occasional wrinkles. However, the Greenlandic specimens possess a small spine on the posterodorsal margin (Skovsted 2006, fig. 6.8, 6.9). Specimens from the NB section with well-preserved margins are rare, although the few specimens with intact margins (Fig. 20A, C, F) do not show evidence of a posterodorsal spine. The posterodorsal margin is also not well-preserved in the figured type specimen of *L. sayutinae* (Melnikova et al., 1997, pl. 2, fig. 7), so the presence of a posterodorsal spine cannot be confirmed.

Liangshanella sayutinae from the NB section can be distinguished from *L. circumbolina* Topper, Skovsted, Brock and Paterson, 2011 from the AJX-M section (Betts et al., 2016b, Appendix 1), the latter bearing distinctive shallow depressions with circular perforations surrounded by packed papillate structures on the external surface of the shield (Topper et al. 2011b, fig. 5). The external surface of *L. sayutinae* is smooth (although wrinkles may occur in the exterior layer of the shield), and weak reticulation can sometimes be observed on the lateroadmarginal border, neither of which is observed in *L. circumbolina*.

Liangshanella sayutinae bears strong similarities with *Liangshanella birkenmajeri* Wrona, 2009 from glacial erratics on King George Island, Antarctica (Wrona 2009, fig. 10). *Liangshanella sayutinae* and *L. birkenmajeri* share similar overall shape and a well-developed border around the free margin. However, the dorsal fold in *L. birkenmajeri* is curved, not straight as in *L. sayutinae*, and the furrow defining the border around the free margin appears better developed in *L. birkenmajeri* (though this may be a preservational artefact). The surface of the shield in *L. birkenmajeri* is also not well preserved, precluding comparisons of external ornament.

Occurrence: Bystraya Formation, Eastern Trans-Baikal region in Siberia. Bastion Formation, north-east Greenland. Mernmerna Formation, Mt. Chambers region, eastern Flinders Ranges, South Australia; *D. odyssei* Zone (*P. bunyerooensis* trilobite Zone).

Family MONGOLITUBULIDAE Topper, Skovsted, Harper and Ahlberg, 2013

Mongolitubulus Missarzhevsky, 1977

Type Species. *Mongolitubulus squamifer* Missarzhevsky, 1977.

Amended Diagnosis. The diagnosis of Topper et al. (2013b, p. 73) is emended to include amplete within the range of possible valve outlines to accommodate *Mongolitubulus decensus* sp. nov.

Discussion. Spines of *Mongolitubulus* are often found in isolation and have previously been interpreted as protoconodonts (Missarzhevsky, 1977) hyolithelminths (Rozanov, 1986), lobopodians (Dzik, 2003; Caron et al., 2013), and trilobites (Li et al., 2012). The bradoriid origin of at least some of these spines was confirmed with the discovery of *Mongolitubulus unispinosa* Topper, Skovsted, Brock and Paterson, 2007, from the Mernmerna Formation in the Donkey Bore Syncline, central Flinders Ranges (Topper et al., 2007) (DBS section, Fig. 4). This species bears a single spine emerging from the central portion of the shield, which is at least as long at the dorsal fold. *Mongolitubulus* spines possess scales, the arrangement of which is highly variable. Variation in spine shape and microornament, as well as the position and number of spines may be used to distinguish species, but such variation may also be ontogenetic.

Mongolitubulus descensus **sp. nov.** (Fig. 19N-S)

Holotype. Left shield with spine base SAM P53711 (Fig. 19N-P).

Type locality and horizon. CR1/589.7 (Wirrapowie Limestone, *M. etheridgei* Zone) (Betts et al., 2016b, fig. 11, appendix 10).

Diagnosis. Shield amplete or very weakly postplete. Dorsal fold straight. Margins smooth, entire between cardinal corners. Both cardinal corners obtuse. Single spine (~100 µm diameter) located near ventral margin where margin is most strongly convex. Spine at low angle to shield (<45°), curving down toward ventral margin and away from shield surface. Shield surface smooth.

Etymology. Latin *descensus* = to decend; for the initial downward direction of the spine.

Description. Valves amplete to very weakly postplete; subtriangular in outline. Dorsal fold straight. Obtuse angles at both cardinal corners with convex anteroventral and posterodorsal margins. Single, hollow spine (~100 μm diameter) located near ventral margin. Spine with low angle to shield, curving away from shield margin and back toward dorsum. Shield beneath spine depressed, creating a V-shaped trough around spine base that decreases in depth toward the anterior and posterior. Shield smooth, slightly domed over central part. Spine base with pustulose ornament that smooths toward shield.

Material. Two specimens from the Wirrapowie Limestone (*Micrina etheridgei* Zone) in the Flinders Ranges. Both specimens are single left shields, missing the majority of the single spine but retaining spine base. Specimens are derived from MOG/114.1 (63.7 m from the base of the section) and CR1/589.7 (approximate true thickness from base). See Betts et al. (2016b, figs 5, 11, appendices 4, 10).

Discussion. The Mongolitubulidae is now well known from the early Cambrian of South Australia (Skovsted et al., 2006; Topper et al., 2007, 2011b; Betts et al., 2014). Taxa include globally distributed species such as *M. squamifer* (Topper et al., 2011b), *M. henrikseni* and *Spinospitella coronata* (Skovsted et al, 2006), linking strata from the Arrowie Basin with successions in Antarctica, South China, England, Greenland, Mongolia, and North America (Topper et al., 2007). Other species of *Mongolitubulus* currently restricted to Australia includes *M. tunpere* Smith, Brock, Paterson and Topper, 2014 from the Amadeus Basin (Stage 5), *M. anthelios* Betts, Topper, Valentine, Skovsted, Paterson and Brock, 2014, and *M. unispinosa* from the Arrowie Basin (Topper et al., 2007).

Only two specimens of *M. decensus* are known (one each from the CR1 and MOG sections; *M. etheridgei* Zone; Betts et al., 2016b), and neither retain complete spines. Nevertheless, shield and spine base morphology are sufficiently distinctive to warrant recognition and description of a new species. *Mongolitubulus decensus* sp. nov. is similar to *M. unispinosa* in that both bear a single spine. They differ in the position of the spine on the shield; in *M. unispinosa* the spine is centrally located, whereas in *M. decensus* sp. nov. it is located closer to the ventral margin. However, it should be noted that the specimen illustrated by Topper et al. (2007, fig. 6A-F) exhibits some damage to the shield and the spine is bent back toward the dorsal fold, hence the natural position of the spine in relation to the shield is not well understood.

Mongolitubulus anthelios also has a single spine located centrally, but it extends perpendicularly from the shield, rather than at a low angle as in *M. decensus* sp. nov. (see Betts et al., 2014, fig. 8H). The free margin of the shields of *Mongolitubulus anthelios* is curved and bears a toothed ornament (Betts et al., 2014, fig. 8A, O). In contrast, the outline of *M. decensus* sp. nov. is sub-triangular and the shield margin is smooth. *Mongolitubulus unialata* Zhang, 2007 from the lower Cambrian Shuijingtuo Formation in central China also bears a single ornamented spine, although this is located behind an anterior node (Zhang, 2007, 17, figs. 1-8), which is not present in the new taxon. Additionally, the shield outline of *M. unialata* is distinctly postplete, whereas the outline of *M. decensus* sp. nov. is sub-triangular or very weakly postplete.

As mentioned above, neither specimen of *M. decensus* sp. nov. has complete spines, so the distal morphology of which remains unknown. However, the spine base of the specimen from CR1 (Fig. 19N-P) is faintly pustulose. These pustules fade proximally, suggesting that the ornament may become more pronounced along the length of the spine. The specimen from MOG/114.1 was recovered with an isolated spine that bears well-preserved ornament identical to that on spines of *M. anthelios* (larger rhomboid scales interspersed with more numerous stubby scales or pustules; see Betts et al. (2014, fig. 8). Whether this type of ornament also occurs in spines of *M. decensus* sp. nov. remains to be demonstrated with additional, more complete material.

Distribution. Wirrapowie Limestone (*M. etheridgei* Zone), Chace Range CR1/589.7 (approximate true thickness from base) and the Arrowie Syncline (MOG/114.1, 63.7 m from the base of the section) in the Flinders Ranges, South Australia. See Betts et al. (2016b, figs 5, 11, appendices 4, 10).

Family BRADORIIDAE Matthew, 1902

Indiana Matthew, 1902

Type species. Indiana lippa Matthew, 1902.

Diagnosis. See Siveter and Williams (1997, p. 29).

Indiana ?lippa (Fig. 20L-N)

Description. Elongate, postplete shields with gently rounded dorsal cusp. Medium-sized to large bradoriids (~3 mm length). Anterior cardinal corner acute, posterior cardinal corner obtuse. Shield with distinct retral swing. Anteroventral margin and ventral margin gently curved. Posterodorsal margin convex. Posteroventral margin strongly curved. Valve margin most convex at posterior. Short spine on posterior margin. Border and lateroadmarginal furrow both lacking. Shield surface is convex without nodes, lobes or sulci. External ornament covers the entire shield and appears to be granulose, though this may be a result of abrasion.

Material. 46 specimens total; 43 shields and one specimen with both shields held together with matrix from MOG/240.0, two shields from MMT/138.2.

Discussion. The concept of *Indiana* encompasses medium-sized to large, elongate bradoriids with evenly convex shields with a postplete outline and lacking any nodes. External ornament may vary from smooth to punctate or granulose (Siveter and Williams, 1997). The diagnosis of the genus given by Siveter and Williams (1997) defines adults as being *c.* 10-14 mm in length, although the figured lectotype of the type species, *Indiana lippa* Matthew, 1902, is only 5.1 mm long (Siveter and Williams, 1997, pl. 3, fig. 2). Specimens from the MOG and MMT sections are at most 3 mm in length, which is small for this genus. However, average shield size may be biased by style of preservation and method of specimen recovery. Very large shields are more likely to be noticed in hand sample (like much of the material examined by Siveter and Williams, 1997) and are also more likely to suffer breakage during the acid leaching process (for e.g., material examined herein), which may account for the smaller than average size of the specimens from the Arrowie Basin.

The abundant specimens from MOG/240.0 and MMT/138.2 share features with *Indiana lippa*, including the postplete outline, evenly convex shields lacking nodes or sulci, and a dorsal fold that is approximately two thirds of the valve length (Siveter and Williams, 1997). They differ in having a clear dorsal cusp, which is not evident in the type species. Figured crack-out specimens of the type species are not well preserved, which limits morphological comparison (Siveter and Williams, 1997, pl. 3, figs. 2-4). External texture of *Indiana* ?*lippa* from the Arrowie Basin is granulose, though this may be the result of abrasion. *Indiana* ?*lippa* from the Arrowie Basin does not feature punctate shields as in *I. secunda* (Matthew, 1895) and *I. dermatoides* Walcott, 1887. *Indiana secunda* from the

Bastion Formation in north-east Greenland have an ornament of fine punctae that is apparent where external shield laminae have been removed (Skovsted, 2006, fig. 6.11).

?*Indiana* sp. (Fig. 20I-K)

Description. Large, postplete bradoriid (up to 6 mm in length) with straight dorsal fold. Margin on complete specimen is damaged, however anteroventral margin appears concave, ventral, posteroventral and posterodorsal margins are convex. Rounded posterior cardinal corner (anterior cardinal corner damaged). Shield outline rounded with shallow trough defining a wide border around free margin. Microornament consists of shallow depressions (~80 μm wide) each bearing a single pustule at their base (Fig. 20I). Microornament best developed on central, convex part of shield and becomes less pronounced toward borders.

Material. One intact right shield SAM P53720, in addition to abundant fragments from RC/140.5. Wirrapowie Limestone, *M. etheridgei* Zone.

Discussion. This taxon is the largest bradoriid recovered in this study. Material is abundant, but largely fragmentary (the largest specimen is a shield fragment ~5 mm in length). Shield morphology differs subtly from specimens of *Indiana* ?*lippa* from the MOG and MMT sections; the dorsal fold is straight rather than slightly curved, the shield is more strongly convex, and the outline is more rounded at the ventral and posteroventral margins, whereas the outline of *Indiana* ?*lippa* is more elongate. The shield margin, while poorly preserved, shows that these specimens bore an admarginal border, not seen in species assigned to *Indiana*. These features suggest that the RC specimens likely belong to a different genus, but they are unlike other large, postplete bradoriid genera (such as *Bradoria*) as they bear a border, and the external ornament consists of numerous shallow depressions with small raised pustules in the centre of each (Fig. 20I), rather than pits or concentric striae. *Walcotella* Ulrich and Bassler, 1931 reaches up to 7 mm in length, but bears anterocentral and anterodorsal nodes, neither of which are observed in the RC specimens. For the time being, these specimens are tenatively assigned to *Indiana*.

Distribution. Wilkawillina Limestone (Winnitinny Creek Member); Arrowie Syncline, northern Flinders Ranges (MOG section), Bunkers Range, central Flinders Ranges (MMT section), South Australia, *M. etheridgei* Zone.

Family HAOIIDAE Shu, 1990

Jixinlingella Lee, 1975

Type species. Jixinlingella clithrocosta Lee, 1975.

Diagnosis. The diagnosis of Zhang (2007, p. 136) is emended to include taxa possessing a smooth margin in addition to a marginal frill.

Discussion. The Haoiidae Shu, 1990 originally united multilobate bradoriids from China (Shu, 1990). Haoiids now known from the early Cambrian of South Australia include *Haoia* cf. *shaanxiensis* Shu, 1990 (Skovsted et al., 2006) and *Jixinlingella daimonikoa* Betts, Topper, Valentine, Skovsted, Paterson and Brock, 2014. New specimens (herein) are fragmentary, but display the honeycomb network of connecting ridges over the shield and the fine, reticulate microornament on the areas between ridges characteristic of the Haoiidae.

Jixinlingella **sp.** (Fig. 19H-M)

Description. All specimens are fragmentary, but appear to be postplete in outline, gently convex with a smooth margin with narrow lip, and a shallow trough defining a slightly raised border (~150 μm thick). Maximum length of most complete specimen is ~1.80 mm. Dorsal fold is partially preserved in one (conjoined) specimen and seems to be straight. Smooth V-shaped anterior sulcus below which an elongate, narrow node with short spine (tip broken or abraded) occurs. Slight sub-dorsal swelling occurs behind the anterior sulcus. Shield ornamented with smooth ridges forming a polygonal network. These ridges are raised only slightly from the shield surface. Microornament between ridges consists of a very fine reticulate pattern of fine ridges.

Material. Four damaged shields (LMNB/35.3, SAM P53709, LMNB/45.9, SAM P53290 and DBS/102.0, SAM P53710) and one damaged conjoined specimen (MOG/551.5, SAM P53291).

Discussion. These specimens, while poorly preserved, display features that distinguish them from existing species of *Jixinlingella*. The type species, *J. clithrocosta* Lee, 1975 bears a similar network of coarse reticulate ridges, though they are much more strongly expressed

than in *Jixinlingella* sp. Weak ridges with smooth crests may be a result of abrasion, but the relatively well-preserved ornament on the specimen from the MOG section (Fig. 20M) indicates that the feature is likely to be primary. In addition, the ridges in *Jixinlingella* sp. form a more tightly packed arrangement than in either *J. clithrocosta* or *J. daimonikoa* from the MORO section (Betts et al., 2014, fig. 7), and neither of these taxa bear a small spine on the anterodorsal node like that in the new material. *Jixinlingella daimonikoa* also bears a small posterodorsal spine and a frilled margin, not seen in the new specimens.

The coarse ridges of *Jixinlingella* sp. have a more complex arrangement than those in species of *Haoia*. Total number of ridges running dorso-ventrally in *Jixinlingella* sp. is difficult to determine due to the fragmentary nature of the material, but may be up to 6 or 7, whereas *Haoia shaanxiensis*, *H.* cf. *shaanxiensis* (Skovsted et al. 2006) and *Haoia primitiva* only feature 4–5 major dorso-ventral lobes (Shu, 1990, pl. 1, figs. 1-8). This indicates that these specimens are more appropriately accommodated within *Jixinlingella* than *Haoia*.

Jixinlingella sp. from the Arrowie Basin may represent a new species as it displays a combination of morphological features not readily accommodated by either of the existing species of *Jixinlingella*. However, because the anterior of the shield and the dorsal fold are not well preserved in these specimens, they are left under open nomenclature.

Distribution. Mernmerna Formation (*D. odyssei* Zone; approximate *P. tatei* trilobite Zone), Arrowie Syncline, Donkey Bore Syncline and Mt. Chambers Region in the Flinders Ranges, South Australia.

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57

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69

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Timothy P. Topper is a postdoctoral researcher at Durham University, UK. His interests are devoted to unravelling the events surrounding one of the most profound phases of evolutionary change in the history of life on Earth, the Cambrian Explosion. He studied Geology and Palaeontology at Macquarie University, obtaining his PhD in 2010; a thesis focused on Cambrian shelly faunas of South Australia. Since then his research has expanded to include fossil assemblages from Sweden, Denmark, Greenland and North America. His research focus has recently turned from the Burgess Shale Lagerstätte to the Sirius Passet Lagerstätte in North Greenland where he will attempt to decipher the ecological interactions and trophic structure of this early animal community.

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FIGURE CAPTIONS

Figure 1. Extent of the Arrowie Basin, South Australia showing Cambrian outcrop and locations of all measured sections and drill cores used in present study and Betts et al. (2016b). Sections and drill cores included herein are denoted with an asterisk.

Figure 2. SCYW-791A drill core through the Andamooka Limestone on the Stuart Shelf. Ranges of key shelly taxa through the *Dailyatia odyssei* Zone are shown. Abundance data are given in Appendix 1. Note: Key shows approximate stratigraphic relationships of geological units. For detailed stratigraphic information see Betts et al. (2016b, fig. 22), Paterson and Brock (2007, fig. 1) and Gravestock (1995, fig. 7.2).

Figure 3. ER9 stratigraphic section through the Wirrapowie Limestone and Mernmerna Formation in the Elder Range, southern Flinders Ranges. Neither *Dailyatia odyssei* nor *Stoibostrombus crenulatus* occur in ER9 and the presence of the *D. odyssei* Zone is inferred from the ranges of other key taxa, e.g. *A. guillermoi* suggests *P.tatei – P. bunyerooensis* zone age. Note *Pararaia janeae* and associated trilobite taxa occur at the top of the section indicating the presence of the *P. janeae* Zone. Abundance data are given in Appendix 2.

Figure 4. DBS stratigraphic section through the Wilkawillina Limestone and the Mernmerna Formation in the Donkey Bore Syncline, north-central Flinders Ranges. Ranges of key shelly taxa through the *Micrina etheridgei* and *Dailyatia odyssei* zones are shown. Note the presence of the Flinders Unconformity capping the Wilkawillina Limestone. The Linns Springs Member of the Mernmerna Formation rests directly on the Wilkawillina Limestone indicating the absence of the older Six Mile Bore Member due to the disconformity in the DBS section. Inferred *D. odyssei* Zone is therefore projected to the top of the disconformity surface (light green). Abundance data are given in Appendix 3. See also Topper et al. (2007) for stratigraphy and bradoriid fauna from the DBS section.

Figure 5. MMF stratigraphic section through the Mernmerna Formation in the Bunkers Range, central Flinders Ranges. The lower two members of the Mernmerna Formation are missing at MMF due to the erosional/non-deposition surface represented by the Flinders Unconformity. Here, the Third Plain Creek Member (*Pararaia bunyerooensis* trilobite zone) rests directly on the Winnitinny Creek Member of the Wilkawillina Limestone. The *D. odyssei* Zone is indicated by the occurrence of *Stoibostrombus crenulatus* but does not represent the true base of the zone due to the FU, hence the *D. odyssei* Zone has been

76

projected to the top of the disconformity surface (light green) and further sampling is required to confirm the presence of taxa typical of *D. odyssei* Zone. Abundance data are given in Appendix 4. See also Brock and Paterson (2004), Skovsted et al. (2006, 2008, 2009a,c, 2011), Paterson and Brock (2007), Topper et al. (2009, 2010), Larsson et al. (2014) and Jacquet and Brock (2015) for detailed descriptions of shelly fauna (including trilobites) from the MMF section.

Figure 6. 10MS stratigraphic section through the Wilkawillina Limestone and the overlying Mernmerna Formation. The 10MS section is a continuation of the underlying 10MS-W section described by Betts et al. (2016b). Here the lowest member of the Mernmerna Formation (Six Mile Bore Member) rests directly on the Winnitinny Creek Member of the Wilkawillina Limestone; hence the hiatus represented by the FU is likely to be a relatively small time break. Further microstratigraphic sampling is required for confirmation. Abundance data are given in Appendix 5.

Figure 7. BHG stratigraphic section through the Wirrapowie Limestone, Midwerta Shale, lower Mernmerna Formation, Nepabunna Siltsone, upper Mernmerna Formation and the Oraparinna Shale in the south-west Arrowie Syncline, northern Flinders Ranges. Ranges of key shelly taxa through the *Kulparina rostrata*, *Micrina etheridgei* and *Dailyatia odyssei* zones are shown. Note the FU is not developed in the BHG section and the section is interpreted to represent relatively continuous deposition. Distinguishing between the Wirrapowie Limestone and Mernmerna Formation in the field can be difficult (Haslett, 1975). Here, the Midwerta Shale is interpreted as a member within the Wirrapowie Limestone, not the Mernmerna Formation (Gravestock, 1995) based on lithological and faunal data. Abundance data are given in Appendix 6.

Figure 8. RC stratigraphic section through the Wirrapowie Limestone and the Mernmerna Formation in the southern Arrowie Syncline, northern Flinders Ranges. Key shelly taxa through the *Micrina etheridgei* and *Dailyatia odyssei* zones are shown. Note, horizon RC/913.0 contains a mixed and fragmentary shelly fauna and is interpreted to be reworked. Abundance data are given in Appendix 7.

Figure 9. LMNB stratigraphic section through the lower Mernmerna and Bendiuta formations in the Chambers Gorge region, eastern Flinders Ranges. Ranges of key shelly taxa through the *Dailyatia odyssei* Zone are shown. Abundance data are given in Appendix 8.

Figure 10. NB stratigraphic section through the Mernmerna and Moorowie formations in the Chambers Gorge region, eastern Flinders Ranges. Ranges of key shelly taxa through the *Dailyatia odyssei* Zone are shown. Abundance data are given in Appendix 9.

Figure 11. PIN stratigraphic section through the Mernmerna Formation in the Chambers Gorge region, eastern Flinders Ranges. Ranges of key shelly taxa through the *Dailyatia odyssei* Zone are shown. Recovery of *Redlichia* sp. at a spot locality approximately 70 m below the section suggests that the *D. odyssei* Zone extends below the base. Abundance data are given in Appendix 10.

Figure 12. Yalkalpo-2 drill core through the Parachilna Formation, Woodendinna Dolostone, Wilkawillina Limestone and the Mernmerna Formation on the Benagerie Ridge, to the east of the Arrowie Basin (Fig 1). Key shelly taxa through the *Micrina etheridgei* and *Dailyatia odyssei* zones are shown. Abundance data are given in Appendix 11. See also Gravestock, (1995), Gravestock et al. (2001), Zang (2001), Jago et al. (2002), Zang et al. (2007) for additional palaeontological and lithological work on Yalkalpo-2.

Figure 13. Stratigraphic ranges of bradoriids from the Arrowie Basin through the *Kulparina rostrata*, *Micrina etheridgei* and *Dailyatia odyssei* zones. Some bradoriid taxa are restricted exclusively to either the *M. etheridgei* or *D. odyssei* zone, while other taxa have ranges that span multiple zones. Stratigraphic range of *Stoibostrombus crenulatus* is also shown as it is diagnostic of the *D. odyssei* Zone in addition to the eponym (range shown in green).

Figure 14. Shelly taxa of the *Dailyatia odyssei* Zone, Arrowie Basin; *Dailyatia odyssei*, *Stoibostrombus crenulatus* and *Kelanella* sp. A-I, *Dailyatia odyssei* all from the Mernmerna Formation. A, A1 sclerite, NB/58.75, SAM P53616. B, A2 sclerite, LMNB/35.3, SAM P53617. C, A1 sclerite, lateral view, NB/0.0, SAM P53618. D, A1 sclerite, NB/3.3, SAM P53619. E, dextral B sclerite, RC/758.5, SAM P53620. F, C1 sclerite, RC/753.5, SAM P53621. G, C2 sclerite, NB/1.0, SAM P53622. H, C2 sclerite, NB/0.0, SAM P53623. I, C1 sclerite, 10MS/10.0, SAM P53624. J-M, *Stoibostrombus crenulatus*. J-L from the Mernmerna Formation, M from the Andamooka Limestone. J, RC/1057.0, SAM P53625. K, BHG/1513.0, SAM P53626. L, RC/1057.0, SAM P53627. M, SCYW-791A/70, SAM P53628. N-U, *Kelanella* sp., all from the Mernmerna Formation. N and P, RC/913.4, SAM P53629. O, Q, R, T-U, RC/852.0, SAM P53630. S, RC/913.4, SAM P53631.

Figure15. *Eohadrotreta* sp. cf. *E. zhenbaensis* and *Curdus pararaensis* from the *D. odyssei* Zone, Arrowie Basin. A-O, *Eohadrotreta* sp. cf. *E. zhenbaensis*, all from 10MS/571.2, Oraparinna Shale in the Bunkers Graben. A, D and H, ventral valve, SAM P53632. B, ventral valve, SAM P53633. C, ventral valve, SAM P53634. E, dorsal valve, SAM P53635. F and L, dorsal valve, SAM P53636. G, dorsal valve, SAM P53637. I, dorsal valve, SAM P53638. J, ventral valve, SAM P53639. K, dorsal valve, SAM P53640. M, larval shell, SAM P53641. N, close-up of pseudointerarea, SAM P53642. O, shell microstructure, SAM P53643. P-V, *Curdus pararaensis*, A-R, T-U all from AJX-M/415.0, Ajax Limestone, S, from the Andamooka Limestone and V, from the Linns Springs Member of the Mernmerna Formation. P, ventral valve, SAM P53644. Q-R, dorsal valve, with close-up of wrinkled ornament, SAM P53645. S, dorsal valve showing muscle field, SCYW-791A/56, SAM P53646. T, dorsal valve, larval shell, SAM P53647. U, external ornament, SAM P53648. V, interarea, DBS/250.0, SAM P53649.

Figure 16. Shelly taxa from the *Micrina etheridgei* and *Dailyatia odyssei* zones in the Arrowie Basin. *Cambroclavus absonus*, A-G, and H from the Andamooka Limestone on the Stuart Shelf. G from the Mernmerna Formation, Donkey Bore Syncline. A, SCYW-791A/56, SAM P53650. B and H, SCYW-791A/62, SAM P53651. C, SCYW-791A/62, SAM P53652. D, SCYW-791A/64, SAM P53653. E, SCYW-791A/59, SAM P53654. F, SCYW-791A/59, SAM P53655. G, DBS/673.0, SAM P53656. I-L, *Kennarida* sp., both from RC/252.9, Wirrapowie Limestone, *M. etheridgei* Zone. I-J, SAM P53657. K-L, SAM P53658. M-P, *Lapworthella* sp. M, fused sclerites, RC/102.0, SAM P53659. N-P, specimens bearing raised processes on ridges, N-O from DBS/191.0, SAM P53660. P, P from PIN/99.0, SAM P53661. Q, *Camenella reticulosa* from the Mernmerna Formation, RC/852.0, SAM P53662. R-U, Y, Z, AA, Protoconodonts, R-S, both from ER9/16.5, Wirrapowie Limestone, *M. etheridgei* Zone SAM P53663, SAM P53664. T, RC/328.0, Wirrapowie Limestone, *M. etheridgei* Zone, SAM P53665. U, ER9/186.5, Mernmerna Formation, *D. odyssei* Zone, SAM P53666. Y, ER9/67.3, Wirrapowie Limestone, SAM P53670, Z, RC/1119.0, Mernmerna Formation, SAM P53671. AA, ER9/10.8, Wirrapowie Limestone, SAM P53672.V-X, and BB, *Anabarites sexalox*, all from the *D. odyssei* Zone. V, 10MS/462.3, from the Bunkers Sandstone, SAM P53667. W, X and BB, from the Mernmerna Formation, SAM P53668, SAM P53669, SAM P53673.

Figure 17. Mollusc moulds, replaced shells and phosphatic coatings from the *Micrina etheridgei* and *Dailyatia odyssei* zones. A, *Bemella* sp., silicified shell, NB/177.1, Mernmerna

Formation, *D. odyssei* Zone, SAM P53674. B, *Bemella* sp., silicified shell, RC/913.4, Mernmerna Formation, *D. odyssei* Zone, SAM P53675. C, *Tanuella* sp., silicified shell, RC/852.0, Mernmerna Formation, *D. odyssei* Zone, SAM P53676. D, *Marocella mira*, internal mould, ER9/411.7, Mernmerna Formation, *D. odyssei* Zone, SAM P53677. E, *Tanuella* sp., silicified shell, BHG/1301.0, Mernmerna Formation, *D. odyssei* Zone, SAM P53678. F. Indeterminate helcionellid, phosphatic coating, RC/252.9, *M. etherigei* Zone, SAM P53679. G-I and M. *Stenotheca drepanoida*, steinkerns, NB/58.75, Mernmerna Formation, *D. odyssei* Zone, SAM P53680, SAM P53681, SAM P53682. M, *S. drepanoida* steinkern, Mernmerna Formation, *D. odyssei* Zone, SAM P53686. J, Indeterminate helcionellid steinkern, 10MS/407.2, Mernmerna Formation, *D. odyssei* Zone, SAM P53683. K, *Beshtashella tortillis* steinkern, NB/29.0, Mernmerna Formation, *D. odyssei* Zone, SAM P53684. L, *Pelagiella* cf. *madiensis* steinkern, NB/29.0, Mernmerna Formation, *D. odyssei* Zone, SAM P53685. N, *Yochelcionella* sp. steinkern, 10MS/440.0, Bunkers Sandstone, *D. odyssei* Zone, SAM P53687. O, *Pojetaia runnegari* steinkern, NB/29.0, Mernmerna Formation, *D. odyssei* Zone, SAM P53688. P-O, *Yuwenia bentleyi* steinkern, NB/58.75, Mernmerna Formation, *D. odyssei* Zone, SAM P53689.

Figure 18. *Manawarra jonesi* gen. et sp. nov. and *Eozhexiella adnyamathanha* gen. et sp. nov. from the *Micrina etheridgei* and *Dailyatia odyssei* zones in the Arrowie Basin. A-K, *Manawarra jonesi* gen. et sp. nov., all from the Mernmerna Formation, *D. odyssei* Zone. A, left shield, DBS/300.0, SAM P42208. B, left shield, RC/753.5, SAM P53690. C, paratype, conjoined specimen, NB/29.0, SAM P53691. D and I, paratype, right shield and close up of pits, NB/66.6, SAM P53692. E, right shield, PIN/73.5, SAM P53693. F, right shield, RC/913.0, SAM P53694. G, conjoined specimen, 10MS/250.0, SAM P53695. H, phosphatic pads on internal shield surface, NB/66.6, SAM P53696. J, holotype, right shield, NB/58.75, SAM P53697. K, conjoined specimen, NB/29.0, SAM P53698. L-W, *Eozhexiella adnyamathanha* gen. et sp. nov., all from the Mernmerna Formation, *D. odyssei* Zone. L, conjoined specimen, 10MS/90.0, SAM P53699. M, right shield with anterior node, 10MS/90.0, SAM P53700. N, right shield with anterior node, MOG/912.0, SAM P53273. O, conjoined specimen with anterior node, PIN/73.5, SAM P53701. P, paratype, conjoined specimen, MOG/667.4, SAM P53271. Q and S, holotype, conjoined specimen, MOG/667.4, SAM P53272. R, conjoined specimen, MOG/667.4, SAM P53274. T, abraded left shield, 10MS/86-87, SAM P53702. U, paratype, conjoined specimen, MOG/667.4, SAM P53703. V-W, conjoined specimen, MOG/667.4, SAM P51224.

Figure 19. *Acutobalteus sinuosus* gen. et sp. nov., *Jixinlingella* sp. and *Mongolitubulus decensus* sp. nov. from the *Micrina etheridgei* and *Dailyatia odyssei* zones in the Arrowie Basin. A-G, *Acutobalteus sinuosus* gen. et sp. nov., all from the Mernmerna Formation, *D. odyssei* Zone. A, holotype, conjoined specimen, NB/67.3, SAM P53704. B, left shield, NB/66.6, SAM P53705. C and G, left shield with close up of granulose microornament on shield, NB/67.3, SAM P53706. D, specimen with two shields displaced at midline, 10MS/130.0, SAM P53707. E-F, ventral view of conjoined specimen, NB/66.6, SAM P53708. H-M, *Jixinlingella* sp., all from the Mernmerna Formation, *D. odyssei* Zone. H, K and L, damaged right shield with close up of spine on anterior node, LMNB/35.3, SAM P53709. I, probable left shield, margins damaged, DBS/102.0, SAM P53710. J, probable left shield, margins damaged, LMNB/45.9, SAM P53290. M, conjoined specimen, margins damaged, MOG/551.5, SAM P53291. N-S, *Mongolitubulus decensus* sp. nov., both from the Wirrapowie Limestone, *M. etheridgei* Zone. N-P, holotype, left shield with spine base, CR1/589.7, SAM P53711. Q-S, left shield with spine base, MOG/114.1, SAM P53712.

Figure 20. *Liangshanella sayutinae*, ?*Indiana* sp. and *Indiana* ?*lippa* from the Arrowie Basin. A-H, *Liangshanella sayutinae*, all from the Mernmerna Formation, *D. odyssei* Zone. A, right shield, NB/68.5, SAM P53713. B and D, right shield, NB/66.6, SAM P53714. C and H, left shield with remains of right valve adhered to margin, internal view, NB/1.0, SAM P53715. E, close up of internal margin, NB/58.75, SAM P53716. F, right shield, internal view, NB/131.8, SAM P53717. G, abraded right shield, NB/58.75, SAM P53718. I-K, ?*Indiana* sp., both from RC/140.5, Wirrapowie Limestone, *M. etheridgei* Zone. I and J, broken right shield and close up of microornament, SAM P53719. K, intact but abraded right shield, SAM P53720. L-N, *Indiana* ?*lippa*. L-M, right and left shields, both from MOG/240.3, Wilkawillina Limestone, *M. etheridgei* Zone, SAM P53288, SAM P53289. N, abraded right shield from MMT/138.2, SAM P53286. O-R, ?*Eozhexiella* sp. with filled pits, all from the Wirrapowie Limestone, *M. etheridgei* Zone. O, left shield with damaged margins, CR1/476.0, SAM P53279. P, abraded right shield, CR1/457.0, SAM P53721. Q-R, abraded, damaged left shield, CR1/457.0, SAM P53722.

Figure 21. Global correlation of the *K. rostrata* Zone (yellow), *M. etheridgei* Zone (purple) and *D. odyssei* Zone (green) utilising key cosmopolitan shelly taxa (genera and species). Shelly fauna link South Australia with successions in South China, Siberia, Laurentia and Avalonia. Figure adapted from Steiner et al., (2007, figs 11 and 12); Yuan et al., (2011, table 2); Kouchinsky et al., (2012, fig. 3); Peng et al., (2012, fig. 19.11); Landing et al., (2013, fig.

4); Yang et al., (2013, fig. 5). Dashed lines indicate boundaries are uncertain. Undulating lines indicate unconformities. "Cang" = Canglangpuian.

Table 1. Specimen counts for *Eohadrotreta* sp. cf. *E. zhenbaensis* from the 10MS section.

Table 2. Specimen counts for *Manawarra jonesi* gen. et sp. nov.

Table 3. Specimen counts for *Eozhexiella adnyamathanha* gen. et sp. nov.

Table 4. Specimen counts for *Acutobalteus sinuosus* gen. et sp. nov.

Table 5. Specimen counts for *Liangshanella sayutinae*.

Table 6. Specimen counts for *Mongolitubulus decensus* sp. nov.

Table 7. Specimen counts for *Indiana* ?*lippa*.

Table 8. Specimen counts for *Jixinlingella* sp.

Table 1.

Eohadrotreta sp. cf. E. zhenbaensis			
Section	**Horizon**	**Dorsal**	**Ventral**
10MS	571.2	12	2
10MS	551.5	8	6
10MS	547.3		2
10MS	541		1
10MS	515		1
TOTAL		**20**	**12**

Table 2.

Manawarra jonesi gen. et sp. nov.							
Section	**Horizon**	**Count**	**+ Fragments**	**Section**	**Horizon**	**Count**	**+ Fragments**
ER9	75.5	1	Y	RC	1119	0	Y
ER9	67.3	2		RC	1057	2	
ER9	63.8	1		RC	913	14	
ER9	53.5	1		RC	852	1	Y
ER9	45.5	1	Y	RC	844	1	Y
ER9	16.5	1	Y	RC	753.5	1	Y
ER9	10.8	2		RC	145.3	0	Y
ER9	8.7	1		RC	140.5	0	Y
ER9	2	1		NB	201.2	16	
DBS	731	1		NB	196.3	0	Y
DBS	703	2		NB	163.2	0	Y
DBS	699.5	11		NB	131.8	3	
DBS	689	11		NB	68.5	1	
DBS	684	24		NB	67.3	16	
DBS	673	27		NB	66.6	10	
DBS	593.5	11		NB	62.5	2	
DBS	589	10		NB	58.75	32	

DBS	392	3		NB	36.8	3	
DBS	340	3		NB	29	2	
DBS	300	1		PIN	73.5	5	
DBS	290	6		PIN	48	1	
DBS	191	6		PIN	32	0	Y
DBS	170	1		PIN	26	1	Y
DBS	151	2		PIN	0	6	Y
DBS	102	2		10MS	440	2	
BHG	1301	1		10MS	260	3	
BHG	1298.5	5		10MS	250	1	
BHG	1238	0	Y	10MS	230	2	
BHG	1022	1		MOG	699.0 (float)	14	
BHG	293	1		MOG	667.4	10	
Total		**140**		**Total**		**149**	
TOTAL SPECIMENS							**289**

Table 3.

Eozhexiella adnyamathanha gen. et. sp. nov.			
Section	**Horizon**	**Count**	**Shield/Conjoined**
MOG	699.0 (float)	1	shield
MOG	667.4	6	conjoined
10MS	86-87	1	shield
10MS	90	1	conjoined
10MS	90	3	shield
PIN	73.5	1	conjoined
TOTAL		**13**	

Table 4.

Acutobalteus sinuosus gen. et. sp. nov.			
Section	**Horizon**	**Count**	**Shield/Conjoined**
NB	67.3	3	conjoined
NB	66.6	2	conjoined
NB	66.6	6	shield
10MS	130	1	shield
TOTAL		**12**	

Table 5.

Liangshanella sayutinae			
Section	**Horizon**	**Count**	**Shield/Conjoined**
NB	177.1	2	shield
NB	141.5	2	shield
NB	131.8	2	shield
NB	68.5	1	shield
NB	67.3	4	shield
NB	66.6	7	shield
NB	58.75	19	shield
NB	3.3	1	shield
NB	1	4	shield
TOTAL		**42**	

Table 6.

Mongolitubulus decensus sp. nov.			
Section	**Horizon**	**Count**	**Shield/Conjoined**
CR1	589.7	1	shield
MOG	114.1	1	shield
TOTAL		**2**	

Table 7.

Indiana ?lippa			
Section	**Horizon**	**Count**	**Shield/Conjoined**
MOG	240	43	shields
MOG	240	1	conjoined
MMT	138.2	2	shields
TOTAL		**46**	

Table 8.

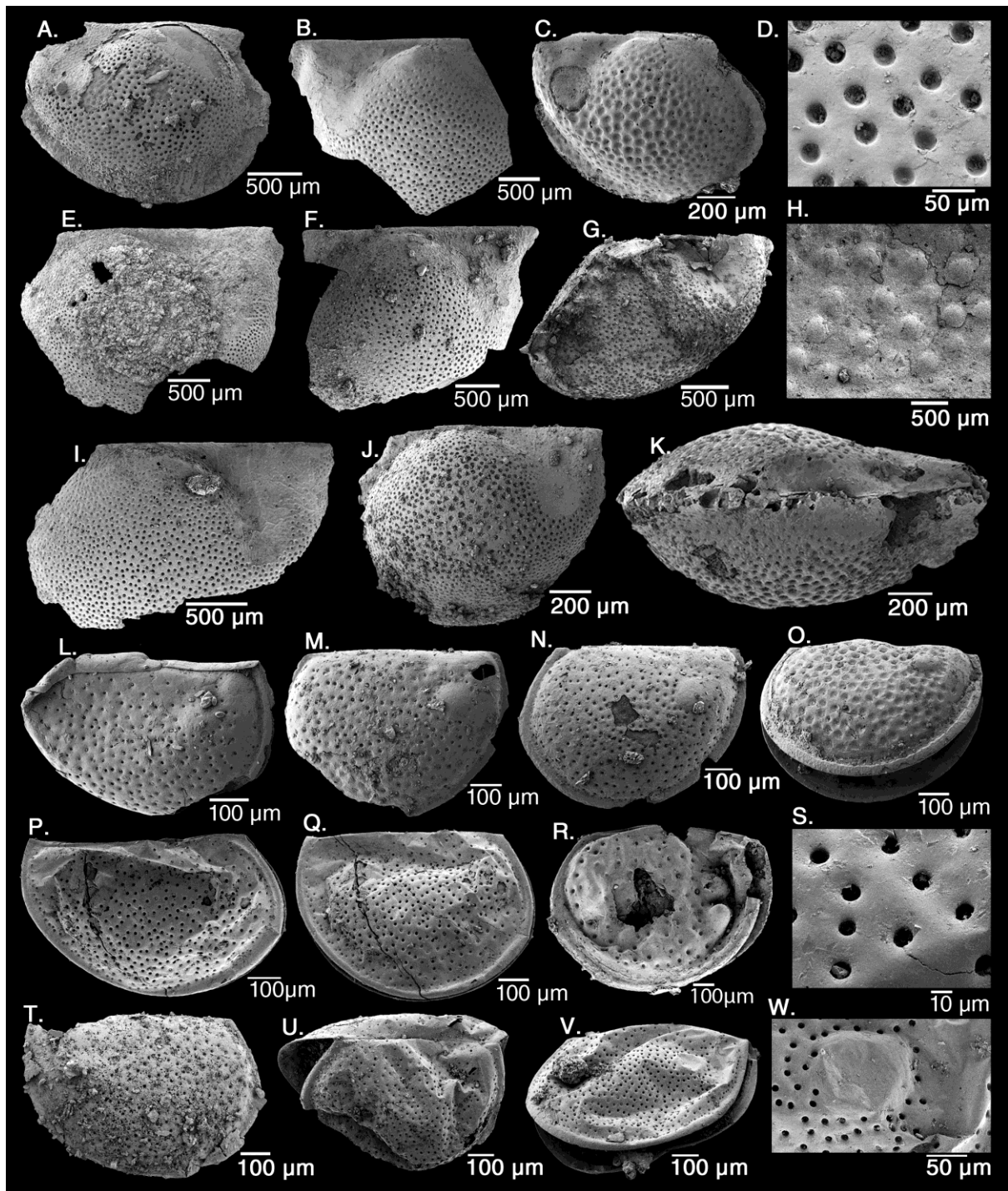| Jixinlingella sp.			
Section	**Horizon**	**Count**	**Shield/Conjoined**
LMNB	45.9	1	shield, damaged
LMNB	35.3	1	shield, damaged
MOG	551.5	1	conjoined, damaged
DBS	102	1	shield, damaged
TOTAL		**4**	
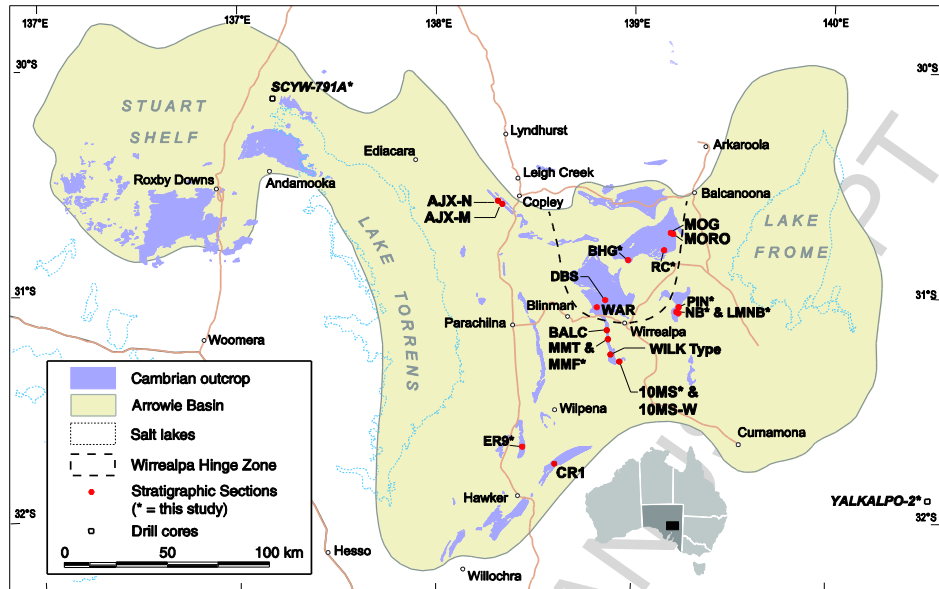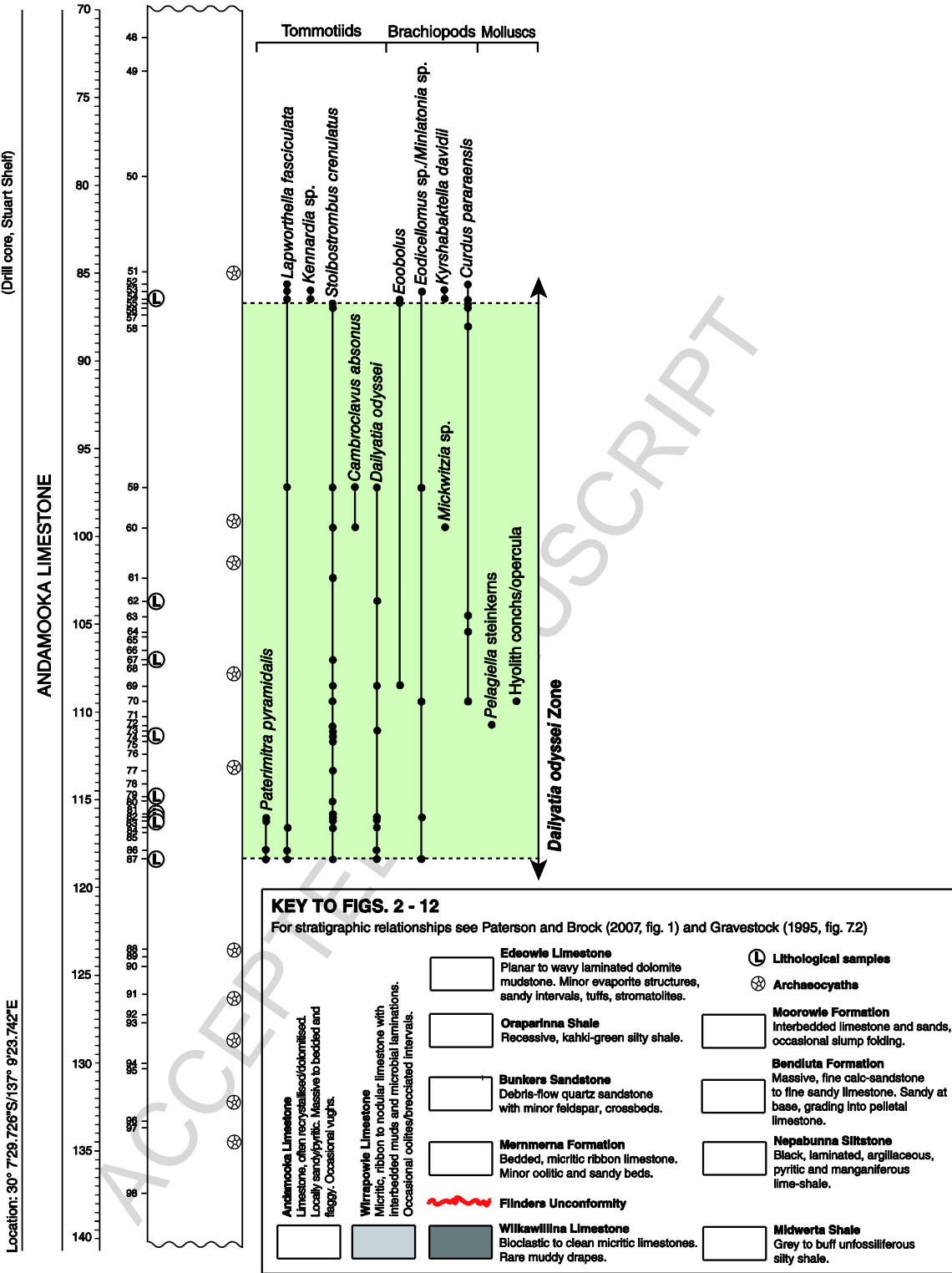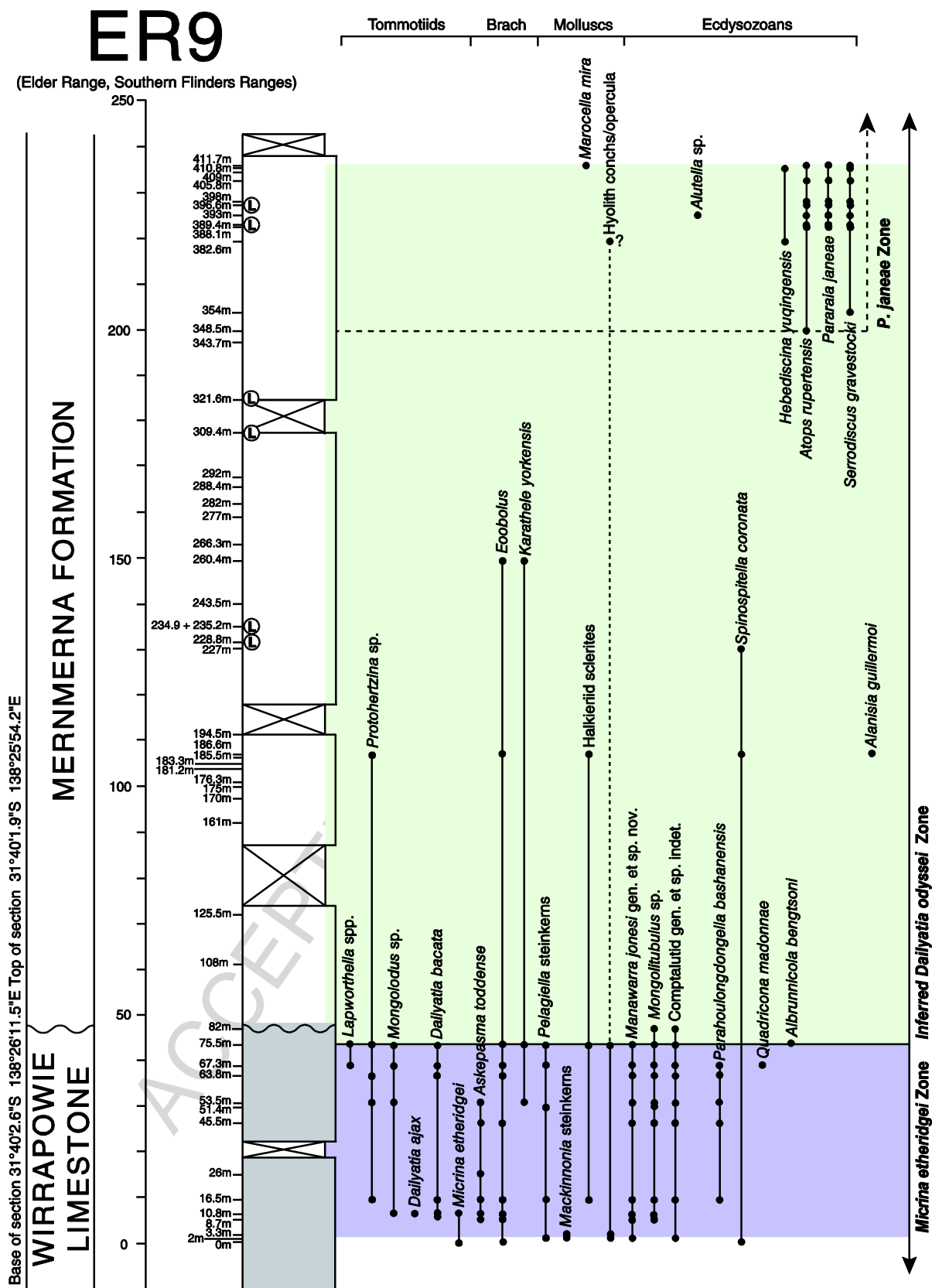
91

Figure 1

Figure 2

Figure 3

93
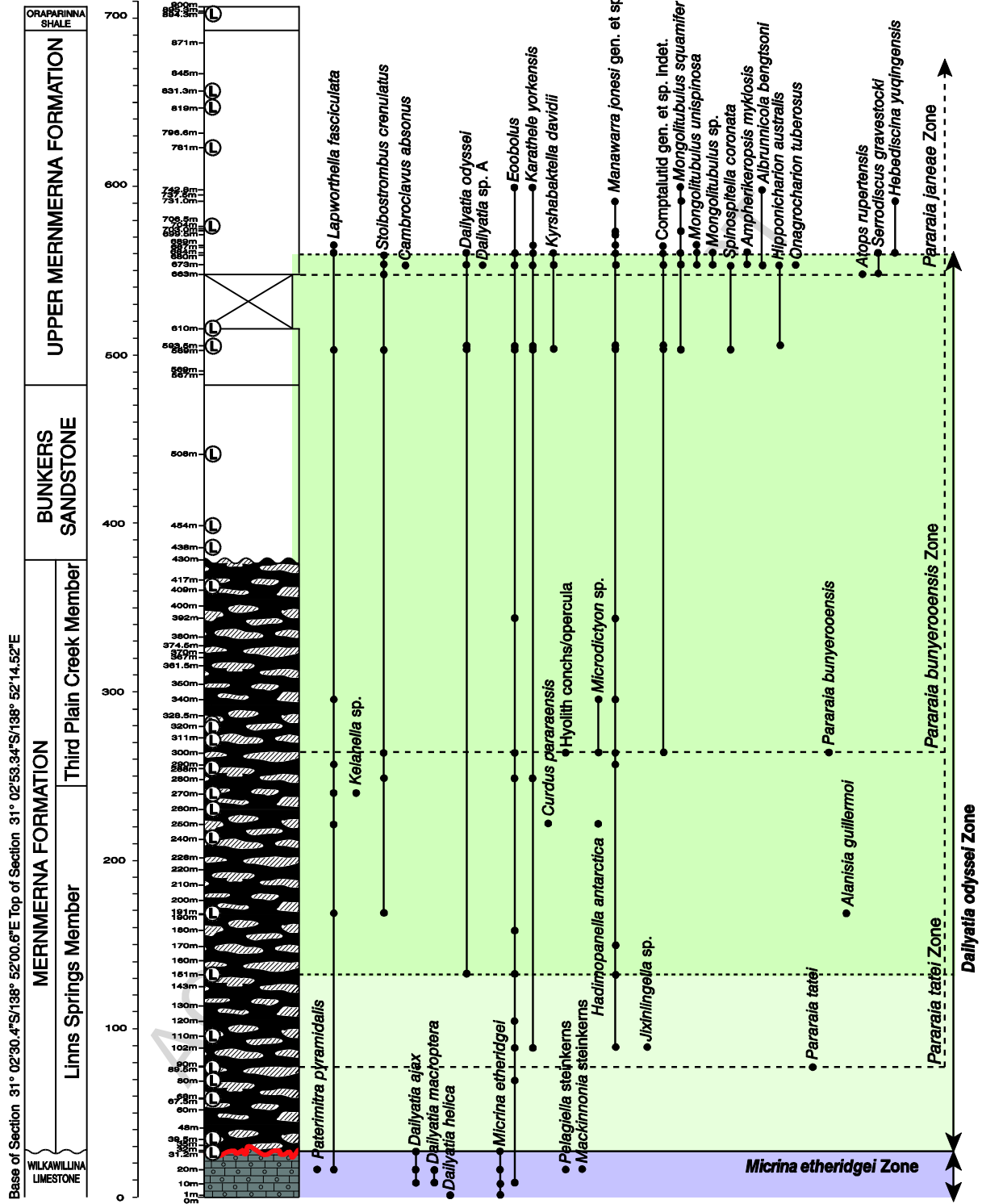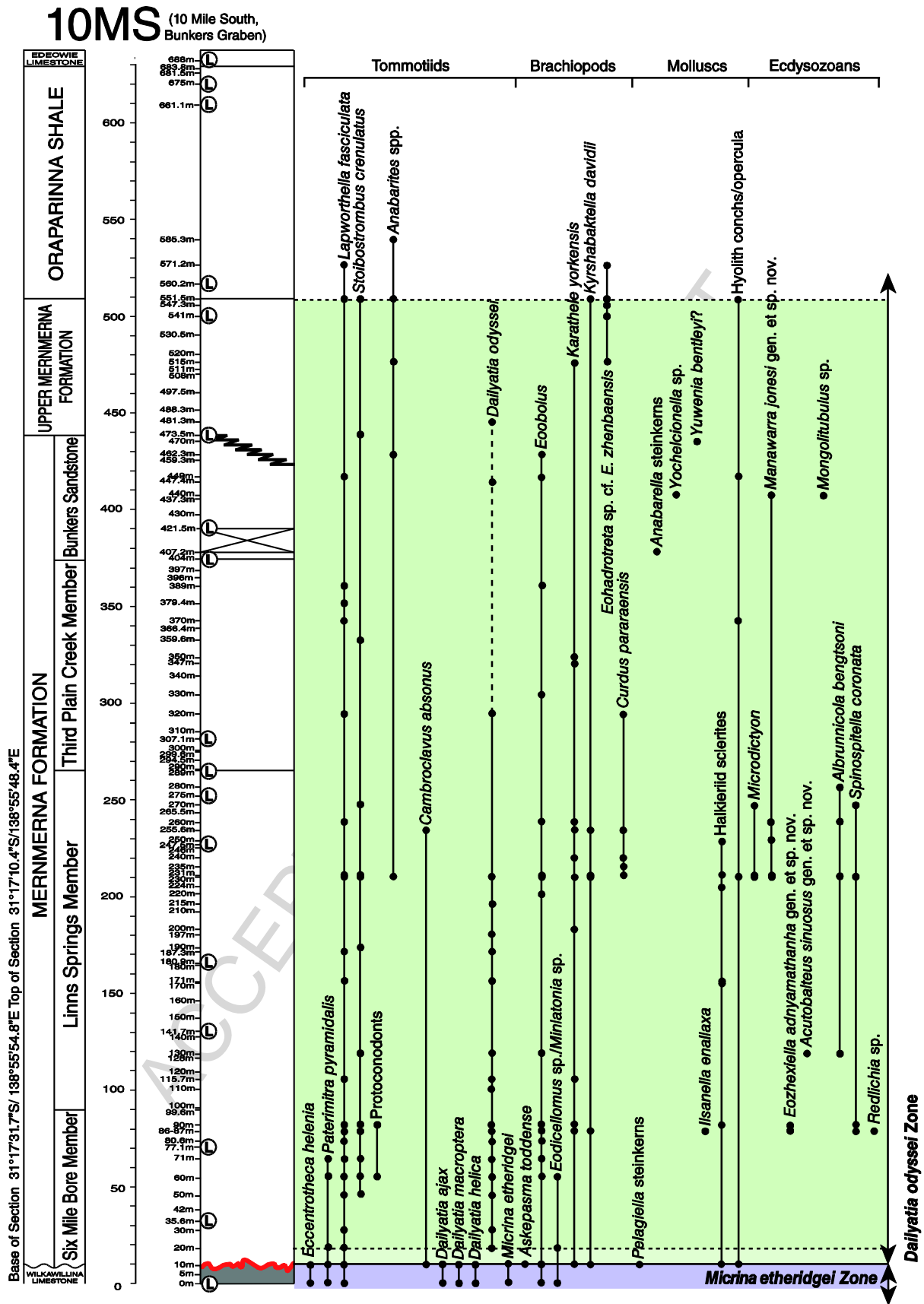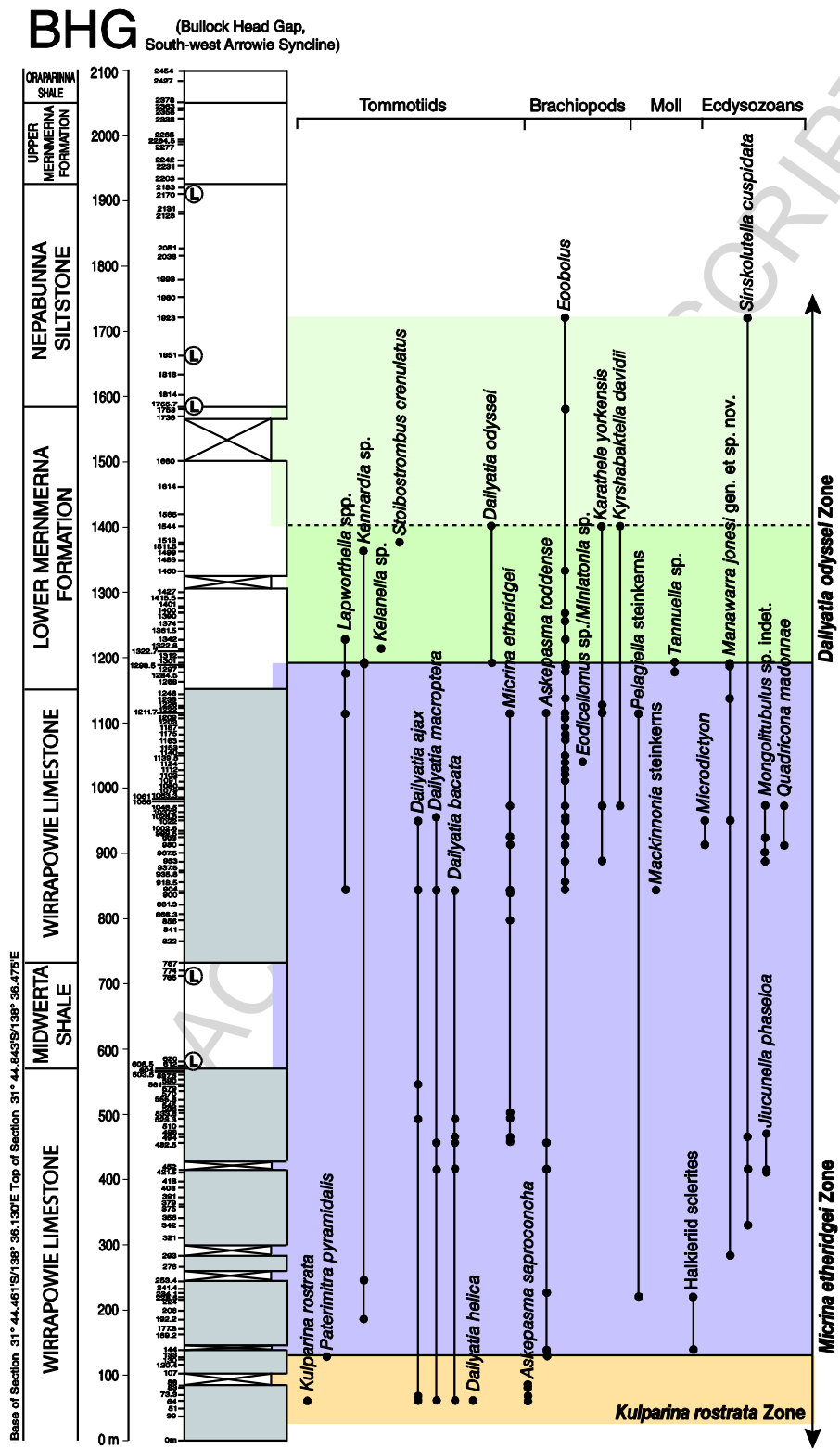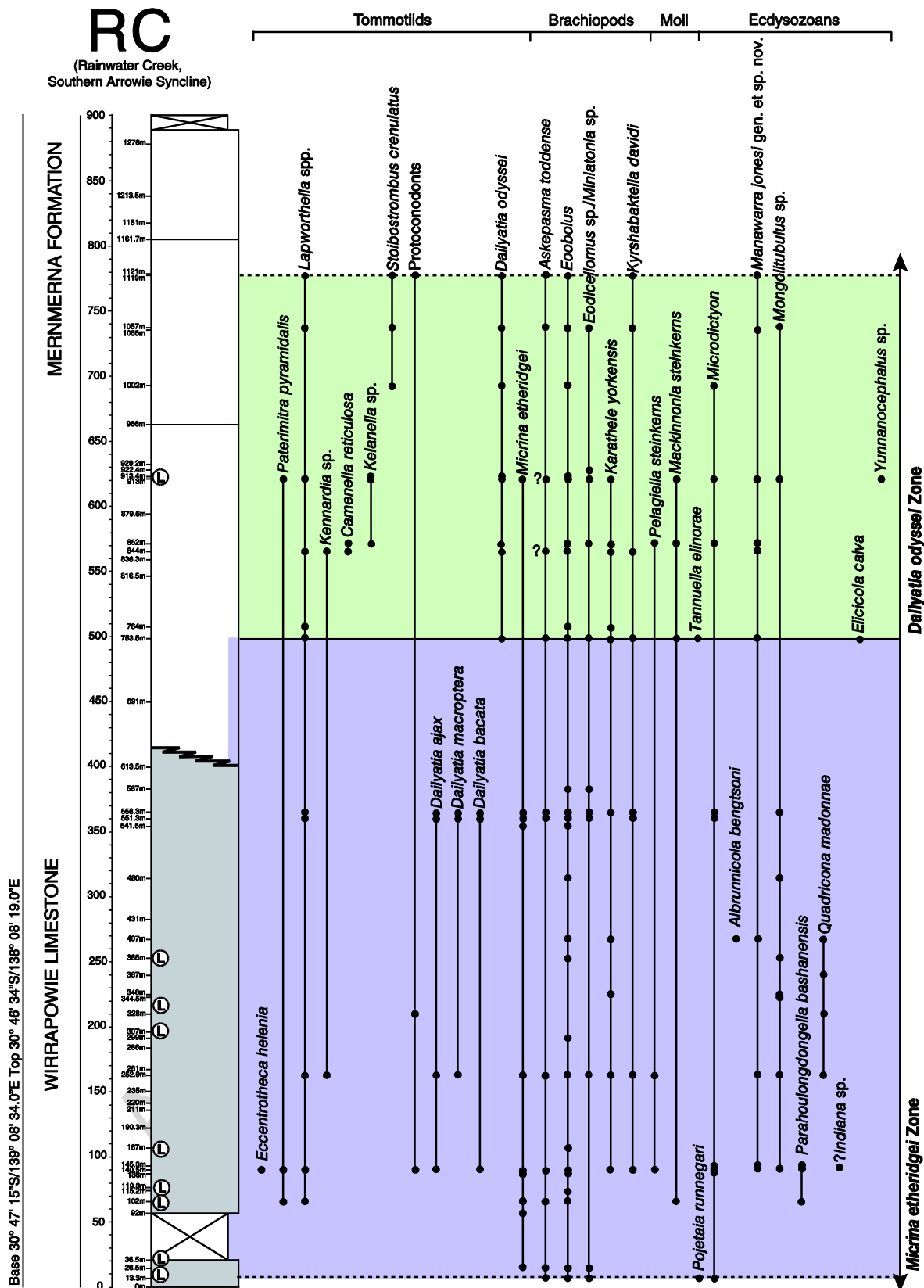
Figure 4

Figure 5

Figure 6
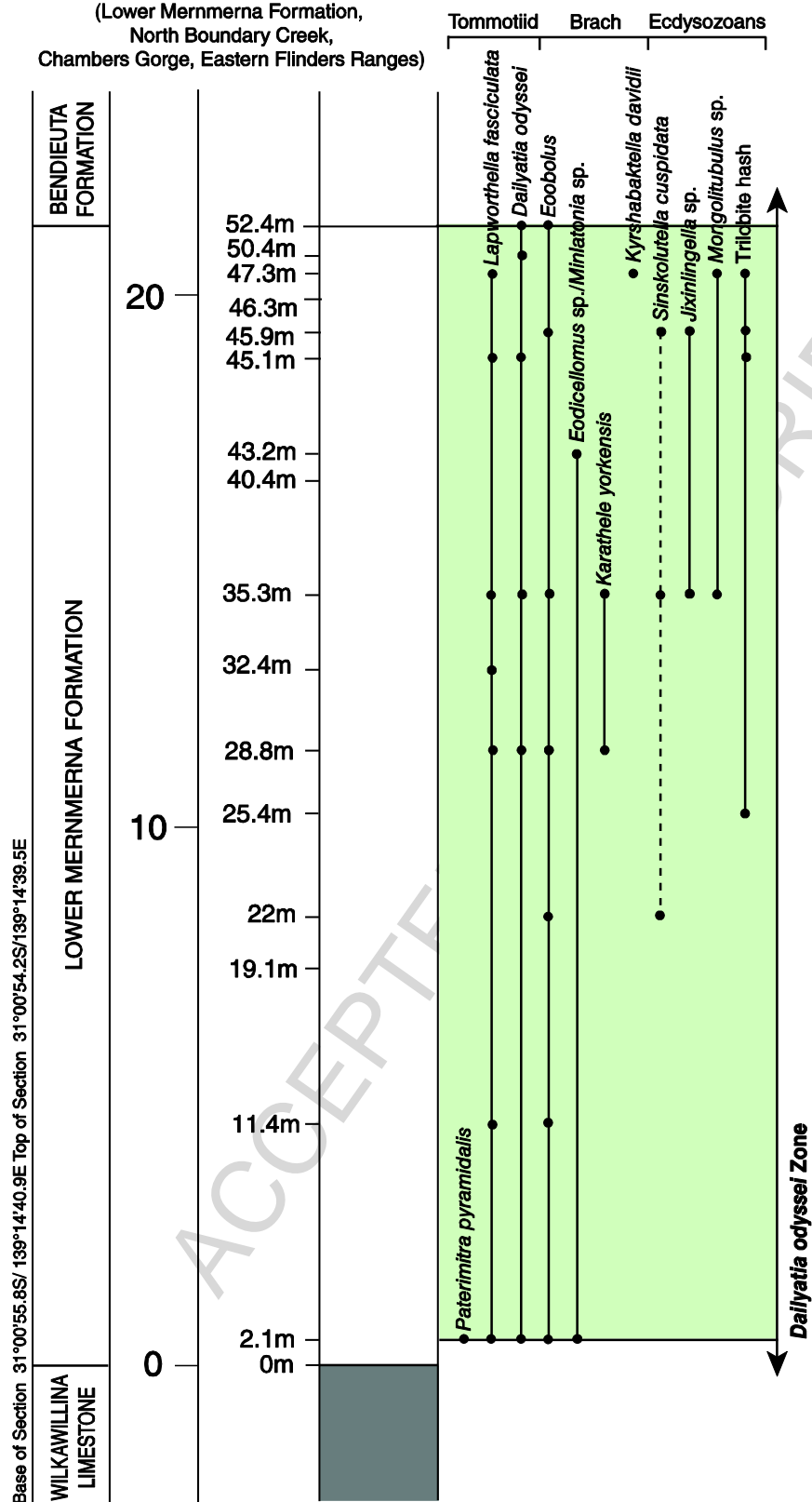
Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

103
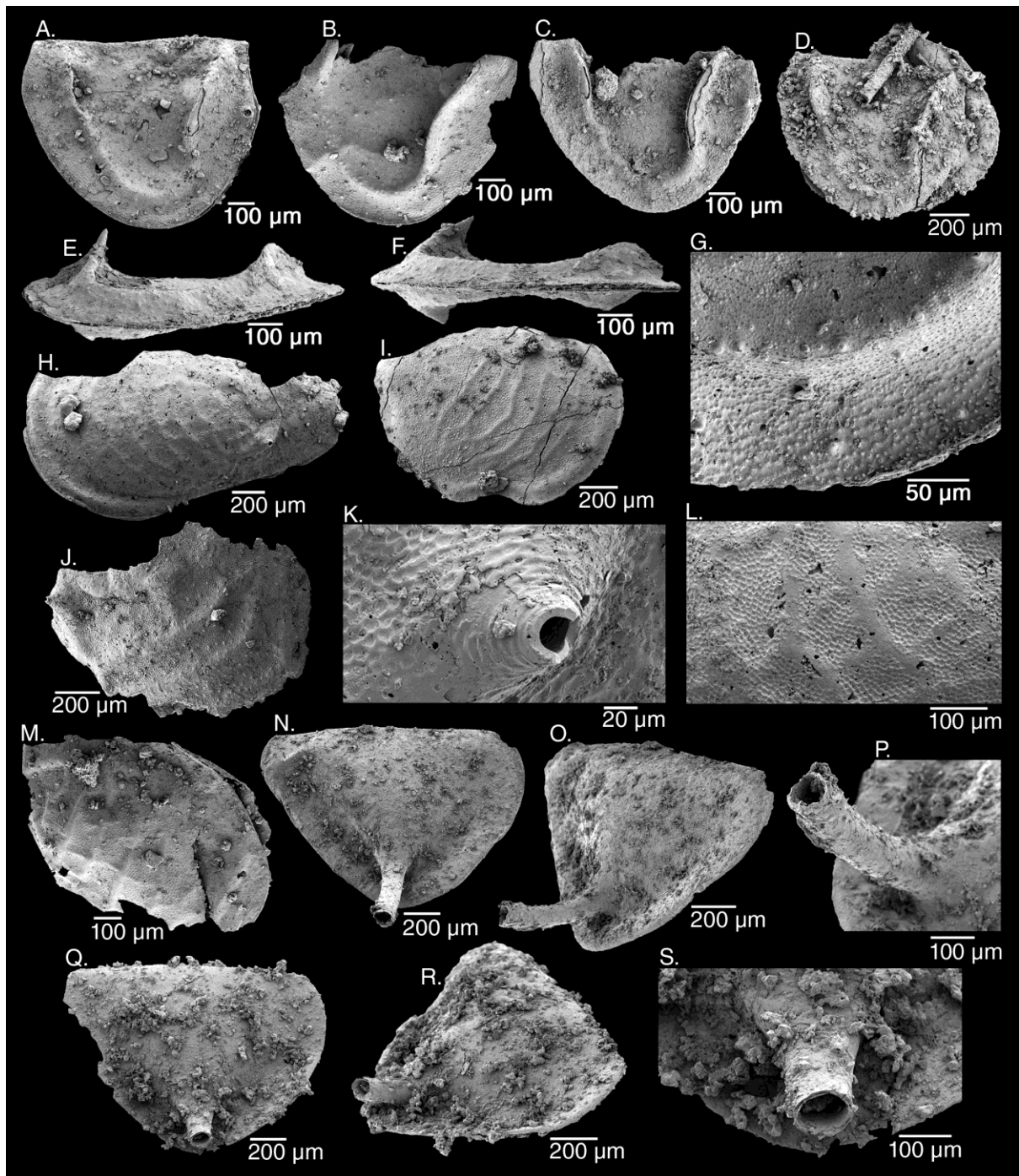
Figure 12

104
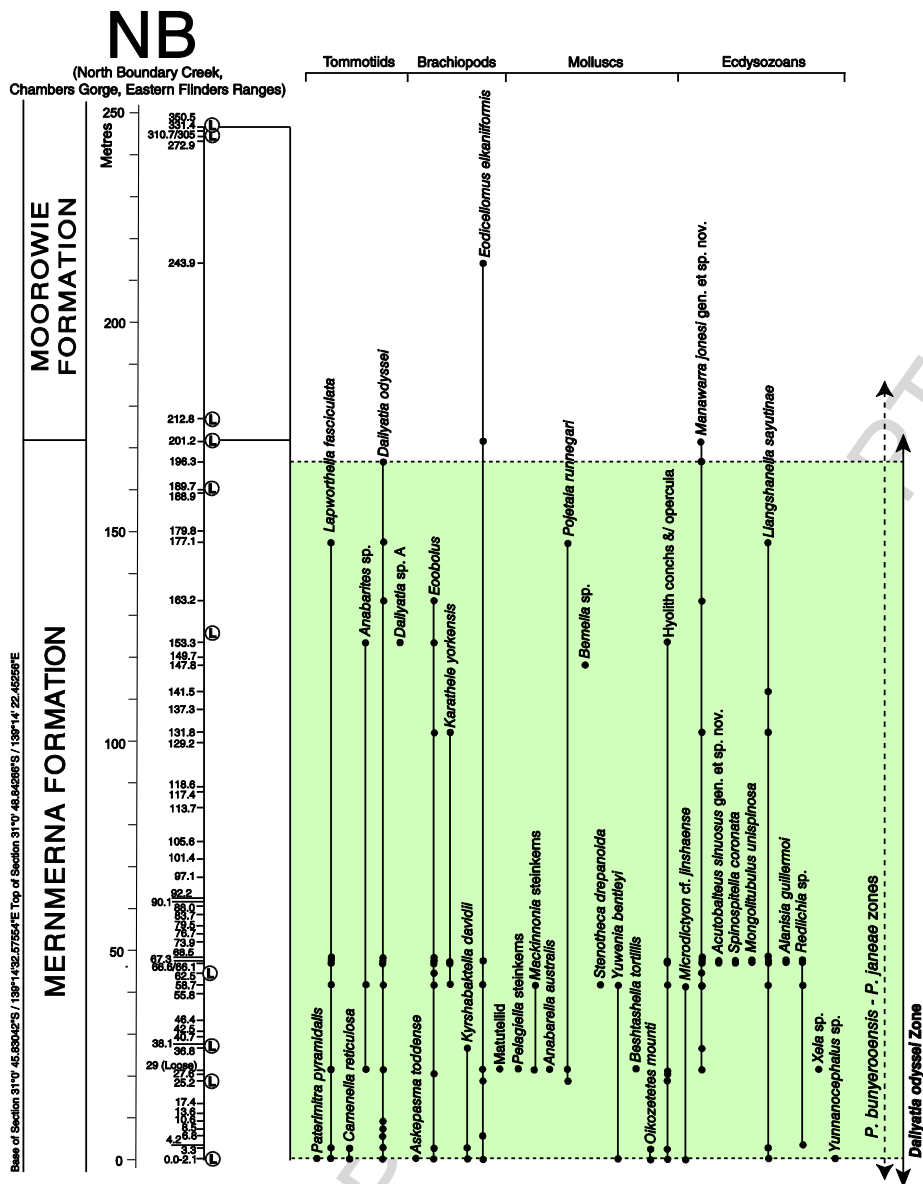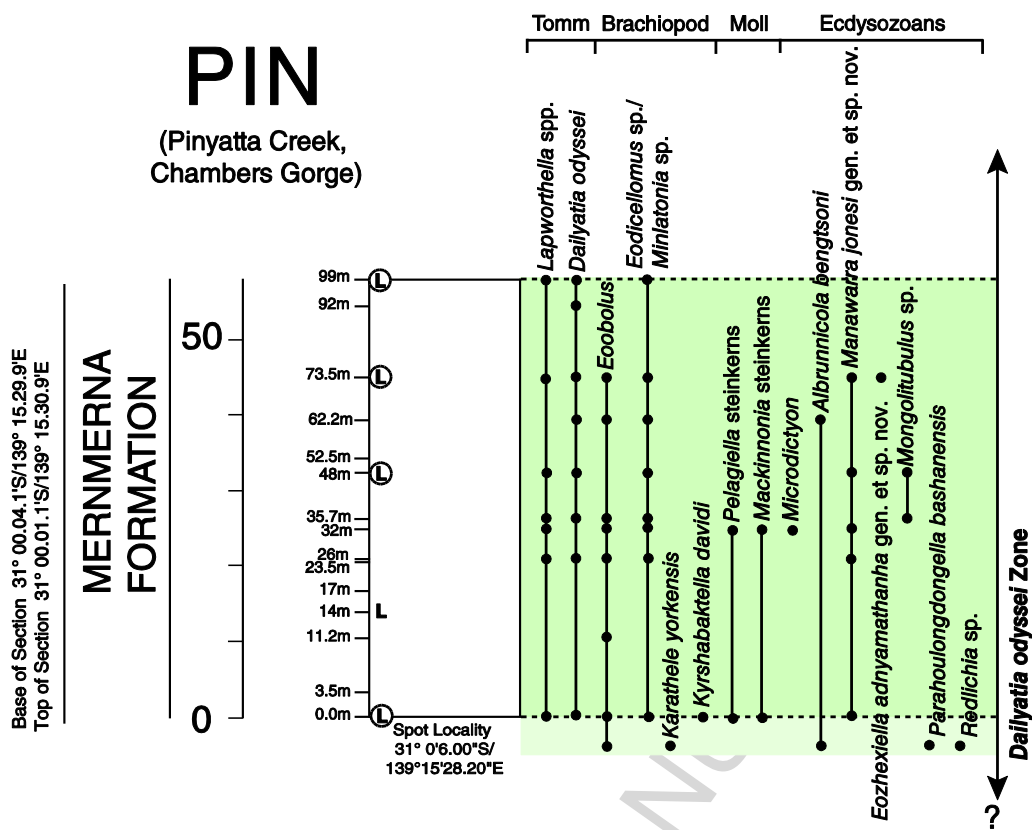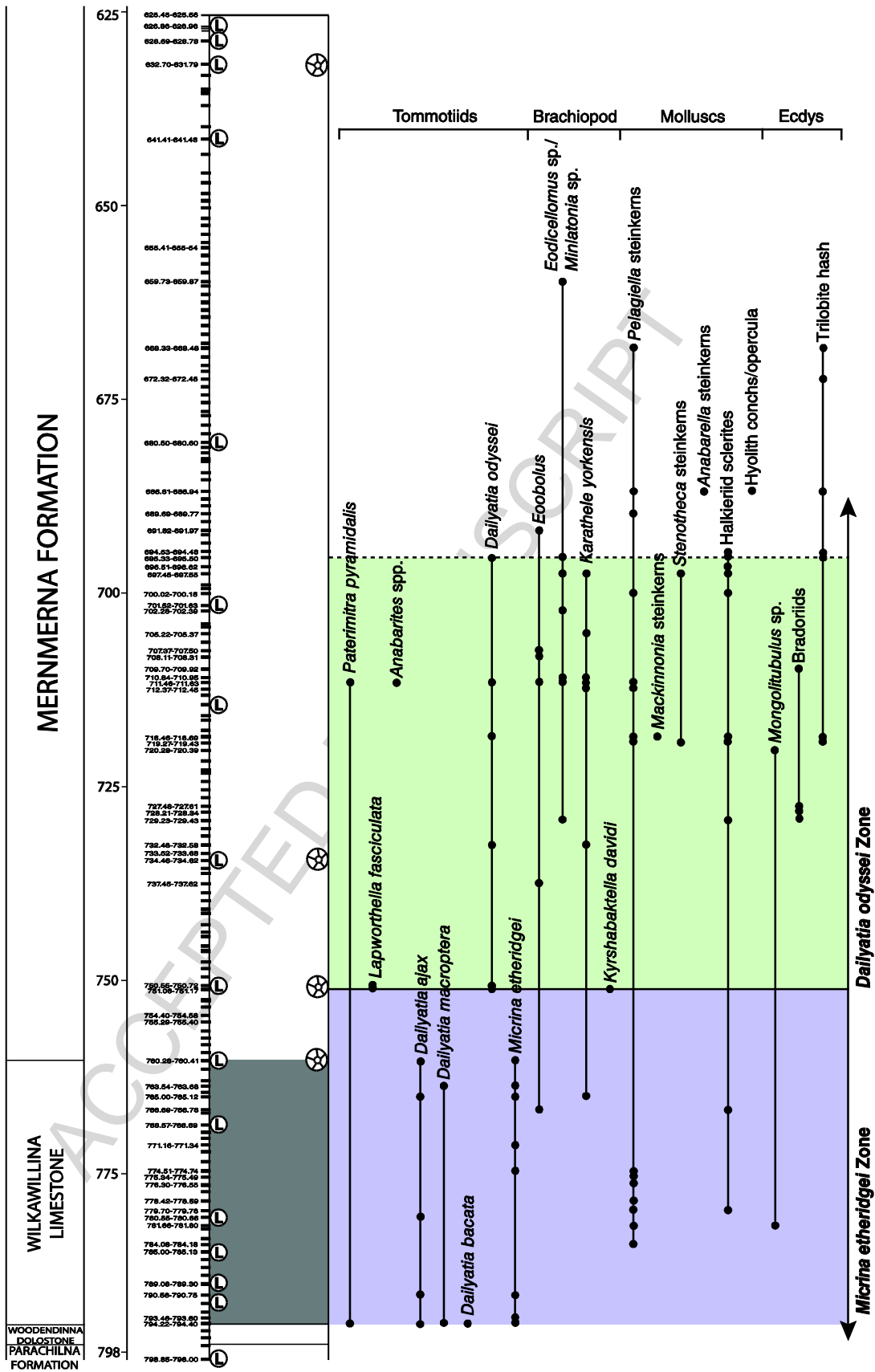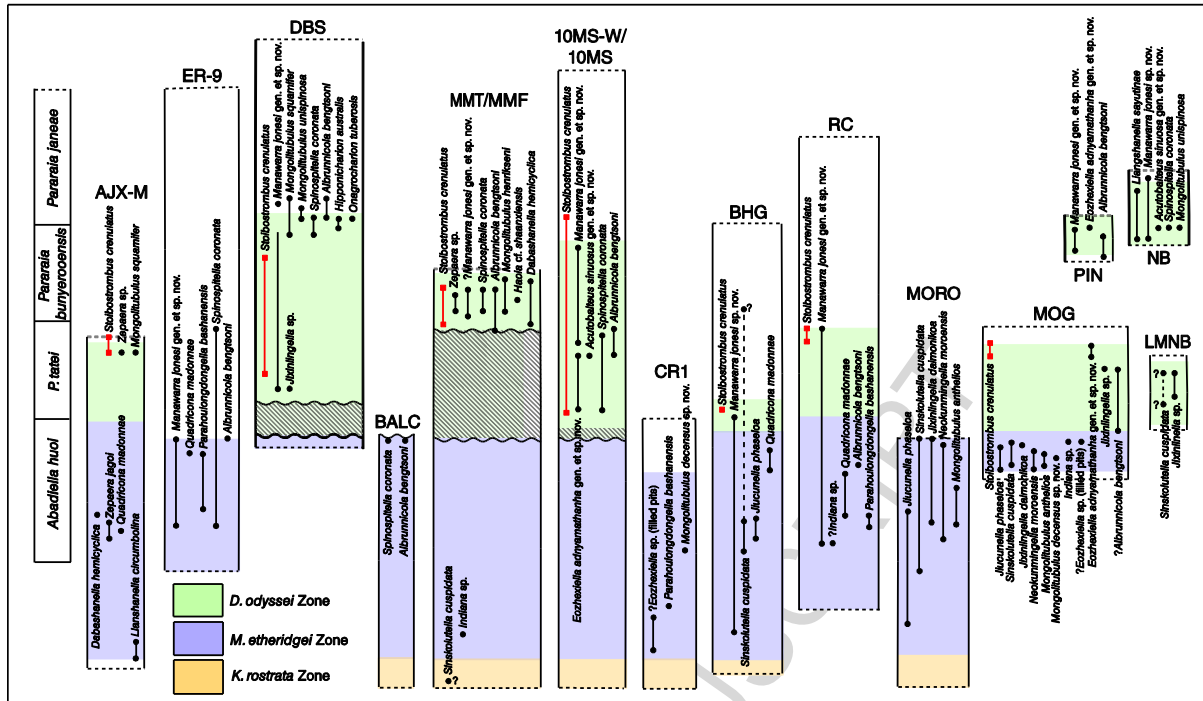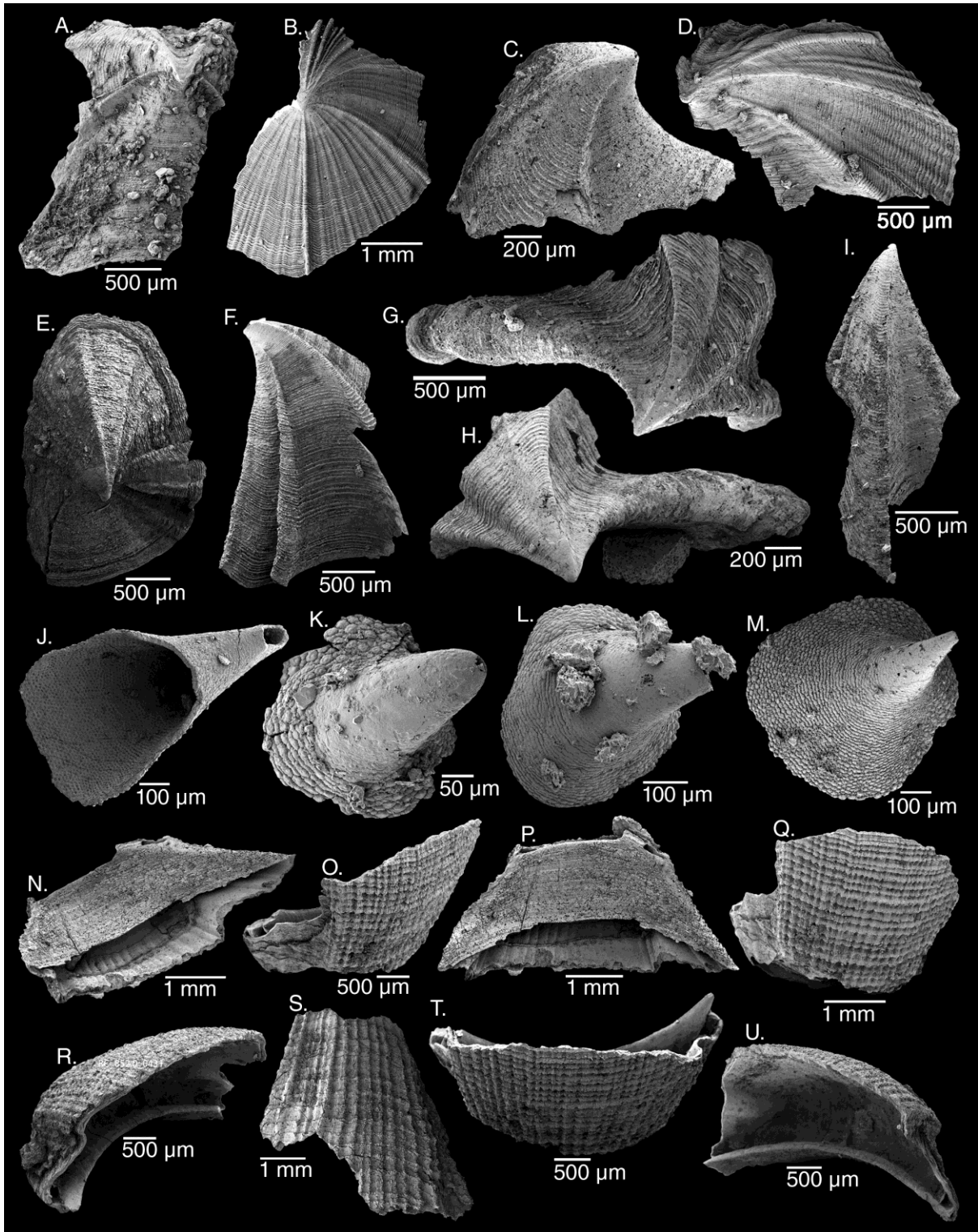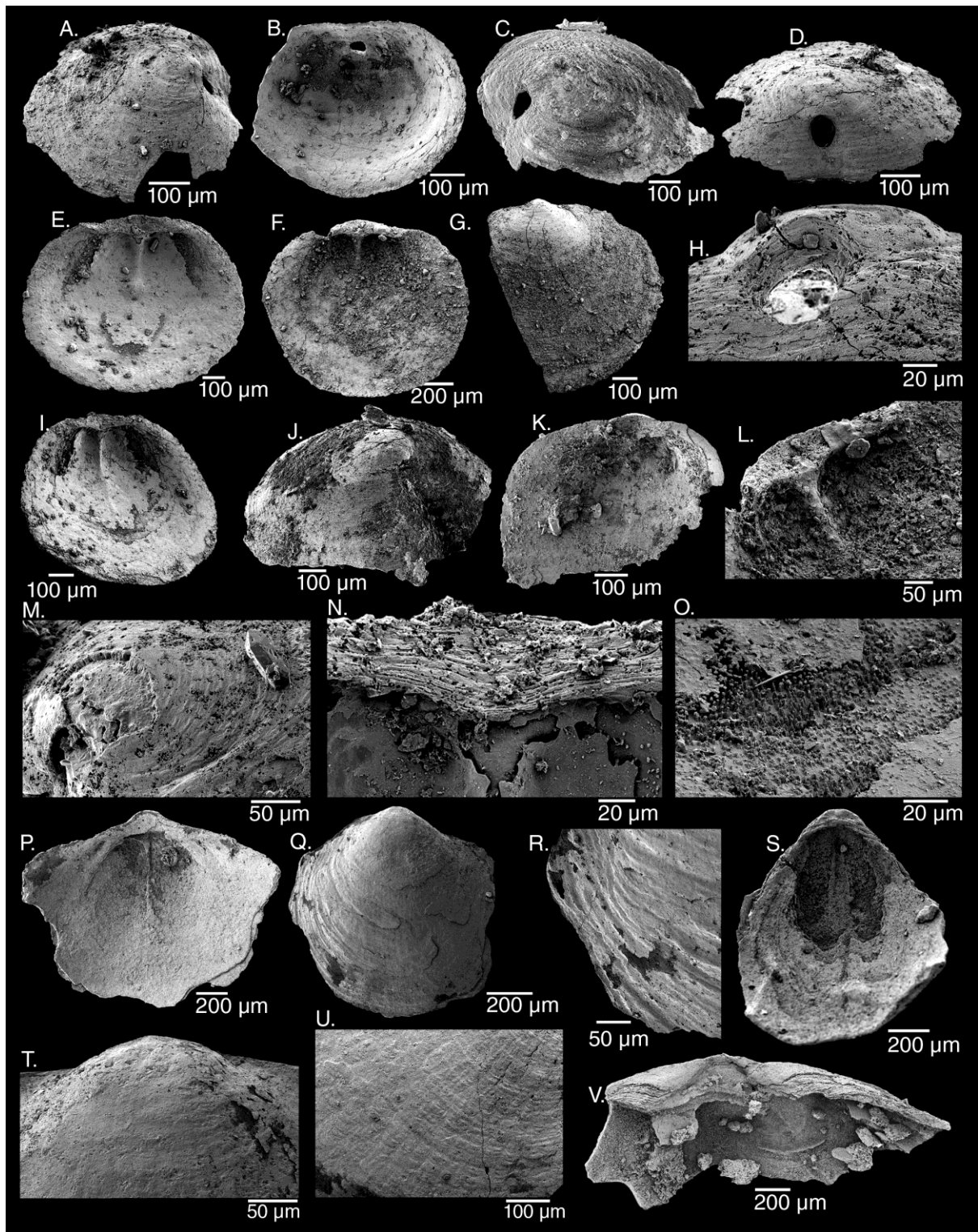
Figure 13

Figure 14

Figure 15

Figure 16
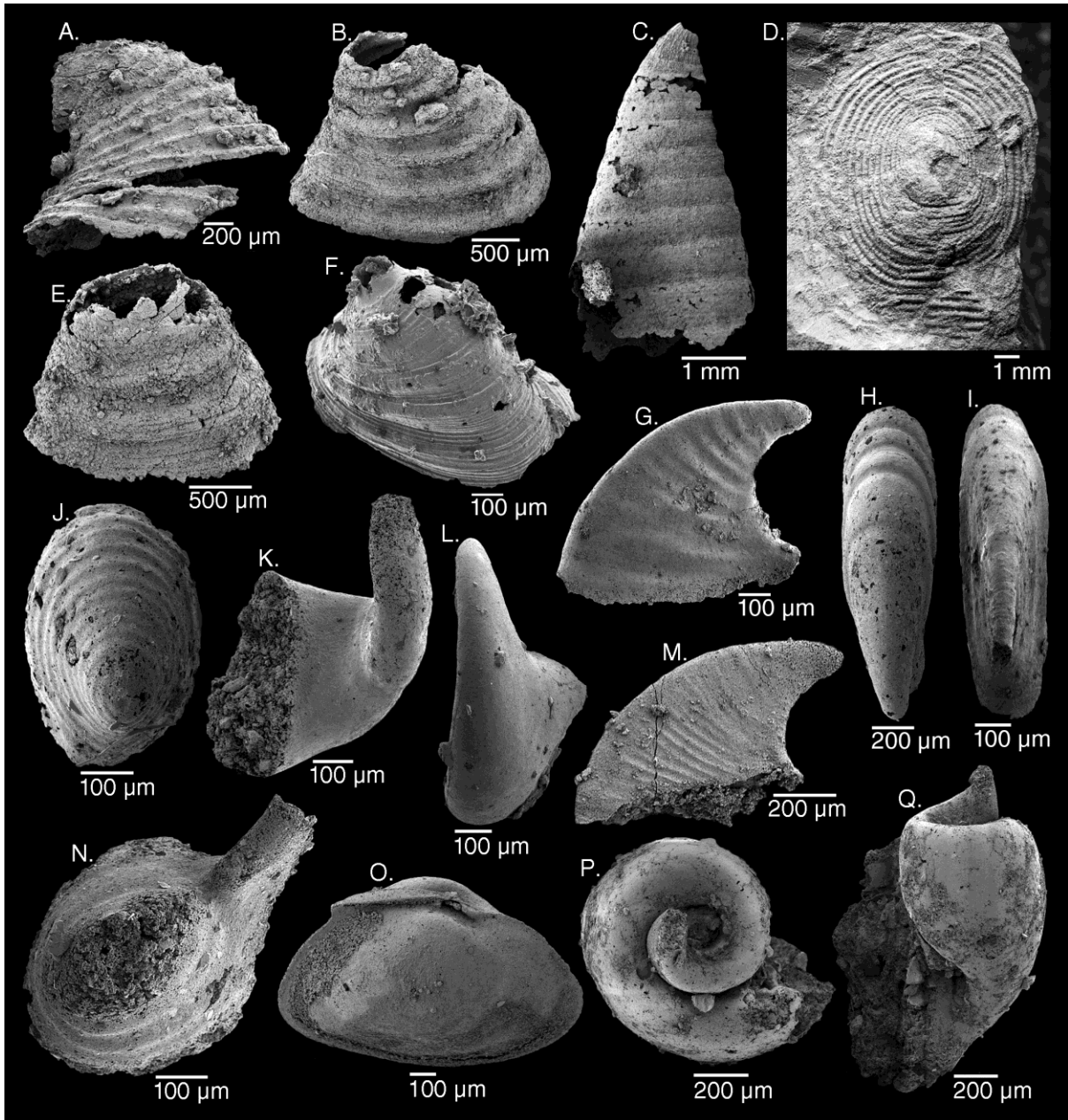
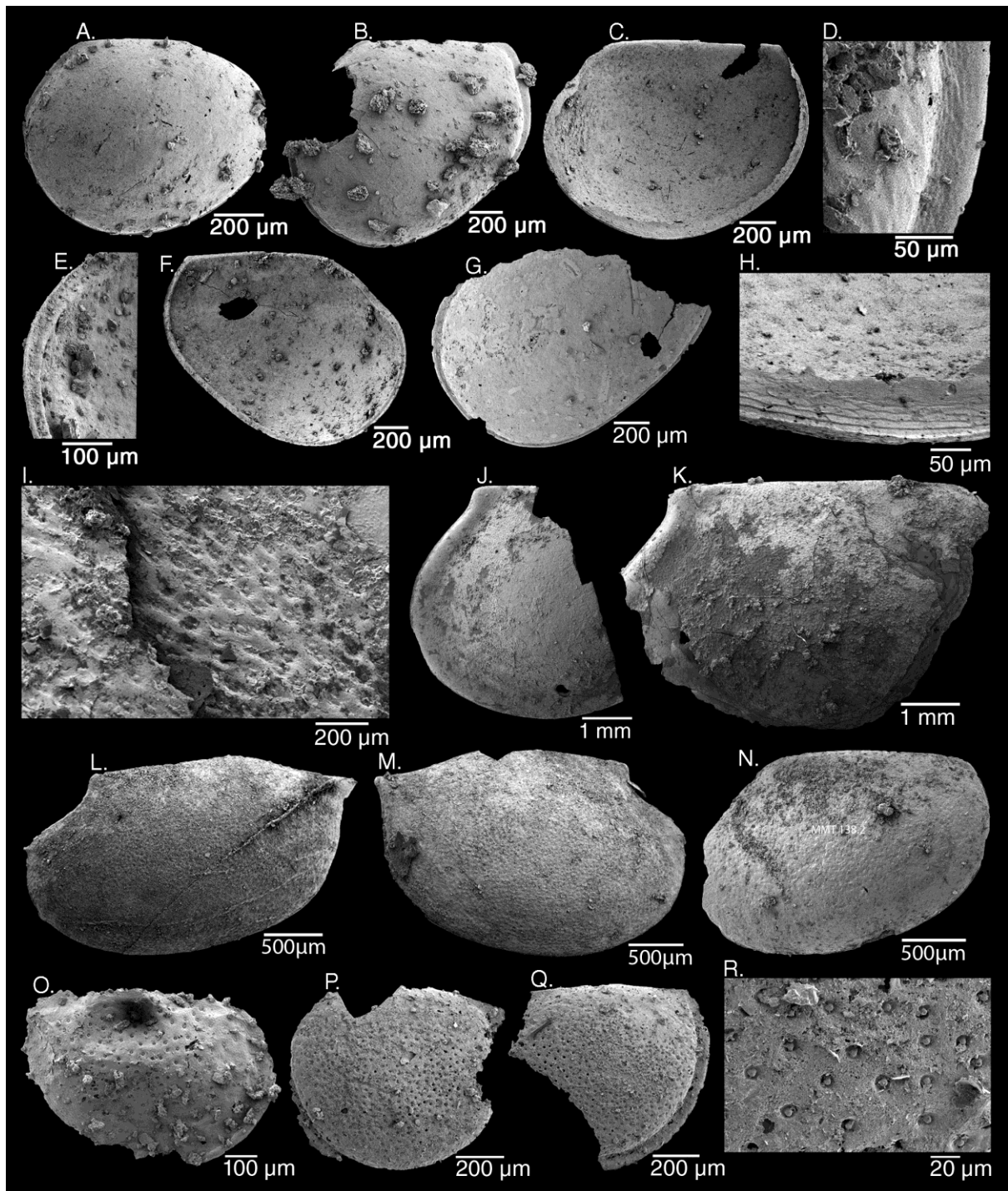Figure 17

Figure 18

111

Figure 19

Figure 20

Figure 21

Graphical abstract
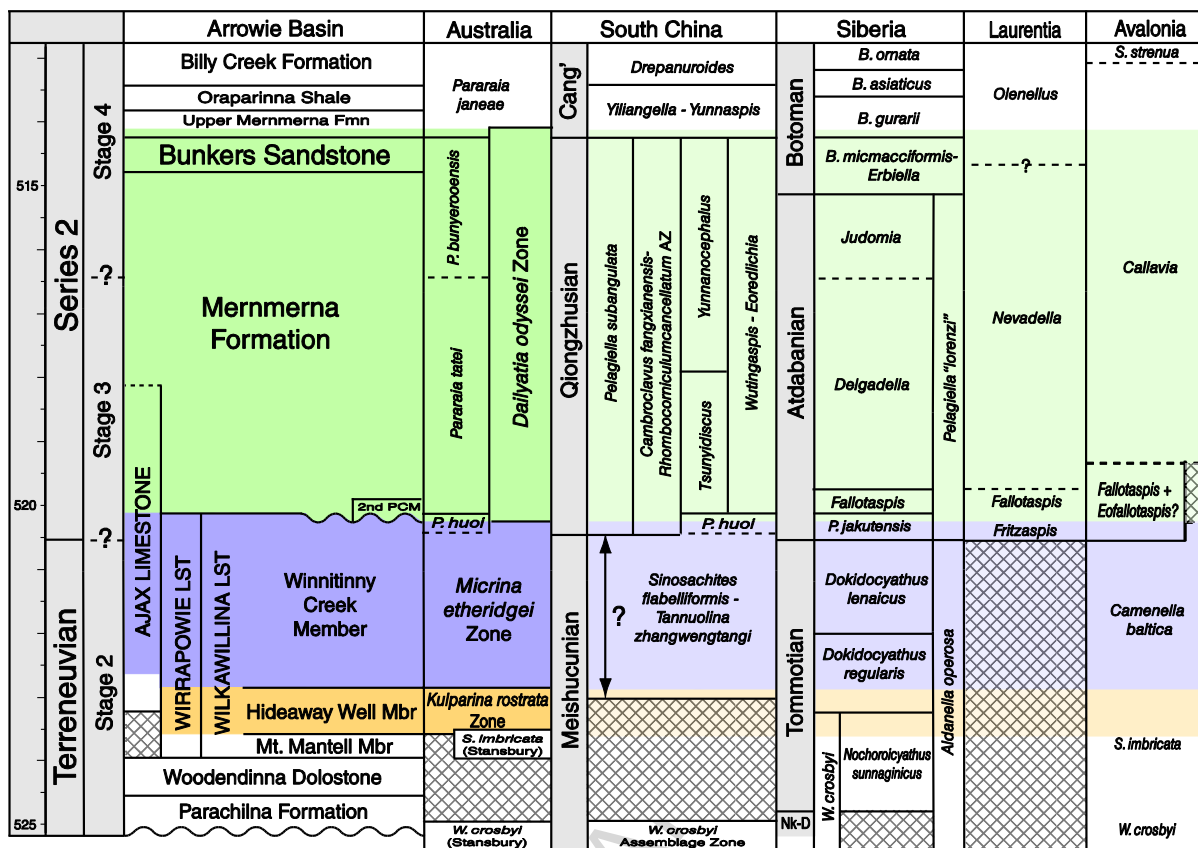
Research Highlights

- Highly diverse assemblage of early Cambrian tommotiids, brachiopods, molluscs, bradoriids and problematica from South Australia.
- Shelly fauna enable global correlation of the *Dailyatia odyssei* Zone (Series 2, Stages 3-4).
- Four new bradoriid species and three new genera are described.