A new early Cambrian bradoriid (Arthropoda) assemblage from the northern Flinders Ranges, South Australia

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Abstract

A new assemblage of early Cambrian bivalved arthropods (Bradoriida) is described from the Arrowie Syncline in the northern Flinders Ranges, South Australia. The well preserved, largely endemic fauna comprises a total of six taxa (including five new species): *Jiucunella phaseola* sp. nov., *Jixinlingella daimonikoa* sp. nov., *Mongolitubulus anthelios* sp. nov., *Neokunmingella moroensis* sp. nov., *Phasolia* cf. *spicata* (Öpik, 1968), and *Sinskolutella cuspidata* sp. nov. This assemblage is derived from a carbonate sedimentary package representing a high energy, shallow water archaeocyath-*Renalcis* biohermal facies of Terreneuvian, Stage 2 age which transitions up-section to a more restricted, low energy, intra-shelf lagoonal environment that correlates with a Cambrian Series 2, Stage 3 age. The new taxon *Jiucunella phaseola* sp. nov., has a first appearance datum (FAD) in shallow water biohermal facies of the Hideaway Well Member of the Wilkawillina Limestone at a level 47 m below the FAD of *Pelagiella subangulata* which is taken to approximate the base of Series 2, Stage 3 in South Australia. Along with *Liangshanella circumbolina*, this makes *J. phaseola* sp. nov. amongst the oldest bivalved arthropods in South Australia and potentially greater Gondwana. The presence of 25 bradoriid taxa from the early Cambrian of South Australia suggests East Gondwana represents a major centre of origin for the Bradoriida.

Keywords: Early Cambrian; Bradoriida; *Abadiella huoi* Biozone; bivalved arthropod; *Pelagiella subangulata*

1.Introduction

Bradoriid arthropods achieved global distribution during the early Cambrian (Williams et al. 2007; 2011) and were significant benthic faunal elements in terms of abundance and diversity during the Cambrian radiation (Siveter and Williams, 1997; Hou et al., 2002; Vannier et al., 2005; Zhang, 2007; Dies Álvarez et al., 2008). Much of the known species diversity is based on specimens derived from both “crack out” material and acid processed carbonates (Shu, 1990; Siveter and Williams, 1997; Williams and Siveter, 1998; Hou et al., 2002; Zhang, 2007; Williams et al., 2007; Topper et al., 2011) and appears to be closely tied to fluctuating oxygen levels on marine shelves throughout the Cambrian (Williams et al., 2011). Recent investigations documenting early Cambrian (Series 2, Stages 3-4) phosphatic skeletal faunas from carbonate shelf facies in the Flinders Ranges, South Australia have revealed an unexpectedly high diversity of bradoriid species (Skovsted et al., 2006; Topper et al., 2007, 2011). Topper et al. (2011) recently described a bradoriid assemblage from the Ajax Limestone in the Mt Scott Range that included *Liangshanella circumbolina*, a taxon that has a first appearance before the incoming of trilobites and the FAD of the widely distributed micromollusc *Pelagiella subangulata* which has been suggested as a potential tool to define the base of Cambrian Series 2, Stage 3. *Liangshanella circumbolina* was recognised as the earliest known bradoriid taxon from East Gondwana. Topper et al. (2011) also revealed a strong provincial signal for bradoriids from East Gondwana, though a clear biogeographic link with South China was also documented.

This study documents a new assemblage of six bradoriid taxa, including five new species from the Arrowie Syncline in the northern Flinders Ranges of South Australia. Many of the genera have Chinese affinities that have not previously been reported from East Gondwana. The new fauna brings the total number of bradoriid genera known from the early Cambrian of Australia to 25, suggesting East Gondwana was a major centre for the origin and early diversification of the group. Of particular significance is the new taxon, *Jiucunella*

phaseloa sp. nov., which has a first appearance datum in the upper part of the Hideaway Well Member of the Wilkawillina Limestone. Regionally, this stratigraphic level is at least equivalent (possibly older) than the FAD level of *L. circumbolina* (Topper et al., 2011) in the Mt Scott Range, and thus indicates *Jiucunella phaseloa* is one of the oldest known bivalved arthropods from East Gondwana. The new assemblage re-enforces generic-level biogeographic links to South China (Topper et al., 2011) and high species endemism of bradoriid faunas in East Gondwana during the early Cambrian.

2. Locality and Lithostratigraphy

Bradoriids described in this study are derived from samples collected along a stratigraphic section (Moro) measured through the lower Cambrian Hawker Group succession in the Arrowie Syncline, northern Flinders Ranges, Arrowie Basin, South Australia (Fig. 1). The Moro section (Fig. 2) is located approximately 5 km south of Moro Gorge on the north-eastern limb of the Arrowie Syncline, a ~25 km long south-west plunging syncline located immediately north of the Stirrup Iron Range. The lower part of the section includes lowstand to transgressive Parachilna Formation and highstand Woodendinna Dolomite of sequence system tract C1.1A of Zang et al. (2004). The base of the Moro section is located at the top of the Parachilna Formation (co-ordinates: 30° 43.616' S; 139° 12.528' E), a well sorted, iron-rich quartz sandstone. The lower 72.5 m of section is obscured by alluvium that covers the contact between the Parachilna Formation and the overlying Woodendinna Dolomite. The Woodendinna Dolomite consists of laminated microbialites, often with muddy interlaminae and centimetre scale digitate stromatolites, though pervasive dolomitisation has destroyed much of the original carbonate fabrics.

101 The Woodendinna Dolostone is disconformably overlain (Jago et al., 2012) by 171 m
102 of the Mt. Mantell Member of the Wilkawillina Limestone. This package is dominated by
103 stromatolites, peloidal carbonates, transported archaeocyath fragments and well-rounded
104 quartz grains reflecting a high energy, shallow water platform environment well above wave
105 base, located relatively close to the palaeocraton. Dolomitisation is present in the upper 40 m
106 of the Mt. Mantell Member in the Moro section (Fig. 2).

107 The contact between the laminated microbialites and stromatolites of the Mt. Mantell
108 Member and the overlying biohermal Hideaway Well Member occurs at 430 m above the
109 base of the section (Fig. 2). The Hideaway Well Member in the Moro section consists of 59
110 m of an archaeocyath-*Renalcis* biohermal facies. These build-ups formed large mound-like
111 structures that measure up to 100 m in lateral extent (an example is transected by the Moro
112 section) and occur for more than 2 km along strike to the north of the section line. Biohermal
113 architecture in the Hideaway Well Member consists of a build-up of closely spaced regular
114 and irregular archaeocyaths bound together by envelopes of encrusting calcimicrobes such as
115 *Girvanella*, *Renalcis* and *Epiphyton*, in addition to irregular archaeocyaths that facilitated
116 sequential biohermal accretion and topographic relief above the surrounding shelf sediments.
117 The flanks of the bioherms are dissected by deep, narrow channels filled with intraclastic
118 carbonate, fragmented shelly debris and micrite that were shed into deeper lagoonal or outer
119 shelf-slope environments. Localised archaeocyath bioherms such as the one transected by the
120 Moro section line are a common feature on the extensive shallow water platform represented
121 by the Wilkawillina Limestone in the Wirrealpa Hinge Zone *sensu* Gravestock and Cowley
122 (1995).

123 Immediately above the biohermal slope facies of the Hideaway Well Member at 564.5
124 m above the base of the Moro section the lithology changes dramatically to a succession of
125 massive carbonate, bioclastic grainstones alternating with micritic and microbial laminated

126 carbonates representing the Winnitunny Creek Member. This distinctive unit is over 135 m
127 thick and suggests a rapid change in depositional environment from a moderate to high
128 energy, shallow water biohermal platform to a more restricted, low energy, intrashelf, and
129 possibly slightly deeper lagoonal environment. Archaeocyaths are relatively rare and
130 sporadically developed throughout this part of the succession (see Fig. 2). The contact
131 between the Hideaway Well Member and the overlying Winnitunny Creek Member is
132 described as disconformable by Clarke (1986) in the type area in the Bunkers Range, but is
133 not immediately apparent in the Moro section.

134 At approximately 701.8 m true thickness above the base of the Moro section (Fig. 2),
135 the upper part of the Winnitunny Creek Member interfingers with, and is partially overlain by
136 the Wirrapowie Limestone. The Wirrapowie Limestone is at least 139 m thick in the Moro
137 section and is characterised by fine-grained ribbon limestones, interpreted to have been
138 deposited in a sheltered lagoonal environment. The lack of cross-beds, desiccation mudcracks
139 or detrital material suggests that this environment remained mostly submerged and stable
140 (Haslett, 1975). The interfingering of units in this part of the Moro section is interpreted to
141 represent partially coeval carbonate deposition, representing different, though likely adjacent,
142 facies in an intracratonic shelf-type setting. A similar interfingering relationship between the
143 upper Wilkawillina Limestone and the Wirrapowie Limestone has been mapped in the
144 Eregunda Creek area in the Wirrealpa Hinge Zone (Haslett, 1975; Gravestock and Cowley,
145 1995; Zang et al., 2004). The distinctive reddened, karstic microstromatolitic horizon at the
146 top of the Winnitunny Creek Member which marks the regionally significant Flinders
147 Unconformity in other parts of the Arrowie and Stansbury Basins (Gravestock and Cowley,
148 1995; Brock and Paterson, 2004; Paterson and Brock, 2007) is absent in the Moro section,
149 possibly reflecting the transitional (and continuous) deposition of laterally interfingering
150 carbonate shelf facies.

3. Age and Biostratigraphy

Paterson and Brock (2007) demonstrated that the FAD of trilobites in the Arrowie Basin, including the eponym of the oldest trilobite zone, *Abadiella huoi* Zhang, 1966, occurs in the upper half of the Winnitunny Creek Member of the Wilkawillina Limestone and equivalent strata in the Ajax Limestone (cf. Topper et al., 2011). The *A. huoi* Zone is equivalent to the *Parabadiella* Zone in China (Jago et al. 2002; Paterson and Brock, 2007) based on the co-occurrence of *A. huoi* in both regions. Traditionally, the *A. huoi* Biozone is considered to be younger than the *Profallotaspis* and *Fallotaspis* zones in Siberia (see Peng et al., 2012, fig. 19.3), though Yuan et al. (2011) have indicated that the *Parabadiella* Zone in China can be interpreted as time-equivalent to the *Eofallotaspis* Zone in Morocco and *Profallotaspis jakutensis* Zone in Siberia. Given the difficulties in defining and correlating the base of Series 2, Stage 3 using trilobites, Peng et al. (2012) have indicated that the FAD of the micromollusc *Pelagiella subangulata* and/or the lobopodian *Microdictyon effusum* could be a useful supplementary proxy for defining this boundary over intercontinental scales. In this regard, it is important to note that the FAD of *P. subangulata* always precedes the base of the *A. huoi* Zone in the Ajax Limestone, Mt. Scott Range (Brock, unpubl. data) and the approximated base in the Moro section (Fig. 2).

The FAD of *P. subangulata* in the Moro section is at 581.7 m above the base of the section in the lower Winnitunny Creek Member of the Wilkawillina Limestone (Fig. 2). This level is taken to approximate the base of Cambrian Series 2, Stage 3 in South Australia (Fig. 2). This horizon is 87 m below the estimated base of the *A. huoi* Zone using small shelly fossil proxy data suggesting that trilobites occur later in Australia than elsewhere (see below). The lack of trilobites in the upper part of the Winnitunny Creek Member of the Wilkawillina

176 Limestone and interfingering Wirrapowie Limestone in the Moro section is presumably
177 facies controlled, but may be a result of sampling bias despite extensive collecting efforts;
178 trilobites are known to be poorly represented in facies associated with the Wirrapowie
179 Limestone (Topper et al., 2011, p. 314). Whilst the lack of trilobites in the Moro section
180 clearly hinders precise correlation, it is possible to at least approximate the position of the
181 base of the *A. huoi* Biozone using the known biostratigraphic ranges of tommotiids and
182 bradoriids as a proxy for age assessment and correlation.

183 Shelly fossils are absent from the Woodendinna Dolostone and Mt. Mantell Member
184 of the Wilkawillina Limestone in the Moro section. Shelly fossils first appear in the Moro
185 section in the lowermost horizons of the biohermal facies in the Hideaway Well Member at
186 sample horizon 570.8, equivalent to 433.48 m true thickness above the base of the section.
187 The fauna includes the oldest known brachiopod from South Australia, *Askepassa*
188 *saproconcha* Topper, Holmer, Skovsted, Brock, Balthasar, Larsson, Petterson Stolk and
189 Harper, (2013a), along with the tommotiids *Dailyatia macroptera* (Tate, 1892) and *Kulparina*
190 *rostrata* Conway Morris and Bengtson, 1990, all of which have FADs considerably below the
191 FAD of trilobites in South Australia (Fig. 2; Jago et al., 2006; Paterson and Brock, 2007;
192 Skovsted et al., 2009; 2011). Topper et al. (2013a) report that *A. saproconcha* occurs in the
193 lower half of the Wilkawillina and Wirrapowie limestones across the Arrowie Basin; these
194 stratigraphic levels can be confidently correlated with pre-trilobitic strata of Terreneuvian,
195 Cambrian Stage 2 age. The FAD of *Askepassa toddense* Laurie, 1986 occurs ~4.5 m above
196 the LAD of *A. saproconcha* in the Moro section. *Askepassa toddense* subsequently ranges
197 through the upper half of the Hideaway Well Member, the entire Winnitunny Creek Member
198 of the Wilkawillina Limestone and into the Wirrapowie Limestone (Fig. 2) which broadly
199 equates with *Abadiella huoi* trilobite Zone.

The stratigraphic ranges of the tommotiids *Kulparina rostrata* and *Eccentrotheca helenia* in the Moro section are perhaps the most instructive and reliable proxies to help constrain the approximate base of the *A. huoi* Zone in South Australia. Based on detailed investigation of the biostratigraphic ranges of these taxa from six separate stratigraphic sections measured through Hawker Group rocks in the Bunkers Graben and Mt. Scott Range, Skovsted et al. (2011, fig. 2, p. 256) demonstrated that *K. rostrata* and *E. helenia* have mutually exclusive stratigraphic ranges. The LAD of *K. rostrata* is invariably located at a level stratigraphically below (sometimes significantly below) the base of the *A. huoi* Zone in all measured sections (Skovsted et al., 2011, fig. 2). The FAD of *E. helenia* occurs within the Winnitunny Creek Member above the LAD of *K. rostrata*. The total stratigraphic range of *E. helenia* is broadly equivalent with the *A. huoi* Zone in the Bunkers Graben and Mt. Scott Range, and the FAD of *E. helenia* is broadly coincident with the FAD of *A. huoi* zone trilobites in all measured sections (see Skovsted et al., 2011).

In the Moro section, the FAD of *Kulparina rostrata* is at 433.8 m true thickness above the base of the section within the Hideaway Well Member, and its stratigraphic range extends into the lowermost Winnitunny Creek Member (LAD 568.3 m true thickness above the base of the section). The FAD of *Eccentrotheca helenia* in the Moro Section is ~100 m above the LAD of *K. rostrata* at 668.7 m true thickness above the base of the section in the Winnitunny Creek Member. In the absence of trilobites in the section, this level is taken as an approximation of the base of the *A. huoi* Zone in the section (Fig. 2).

The first appearance of bradoriids in the fossil record is generally thought to be coincident with, or slightly postdate, that of trilobites around the globe (Williams et al., 2007, 2011; Kouchinsky et al., 2012). A recent global compilation of the stratigraphic ranges of Cambrian bivalved arthropod genera presented by Williams et al. (2011, fig. 4) indicates this interval also corresponds to peak diversification of Bradoriida associated with the Cambrian

Arthropod Radiation Event (CARE; Zhu et al., 2006). It thus seems reasonable to surmise that the actual origin of the Bradoriida precedes this radiation event. The fact that bradoriids appear prior to the defined base of Series 2, Stage 3 based on *P. subangulata* in Australia and trilobite faunas in China (Hou et al., 2002) reinforces a pre-trilobitic origin for the group. Five of the six bradoriids from the Moro section have FADs at stratigraphic levels above the defined base of Series 2, Stage 3 and below the approximated base of the *A. huoi* Biozone (Fig. 2). Importantly, *Jiucunella phaselo* sp. nov. has a FAD in the uppermost Hideaway Well Member of the Wilkawillina Limestone (534.1 m above the base) which is 47.6 m below the Series 2, Stage 3 boundary based on the FAD of *P. subangulata* (Fig. 2). This taxon ranges into the upper Winnitunny Creek Member. The presence of *J. phaselo* in the uppermost Hideaway Well and lower Winnitunny Creek Members of the Wilkawillina Limestone would appear to equate with stratigraphic levels that are at least equivalent or possibly slightly older than the strata yielding *L. circumbolina* in the Ajax Limestone, which has a FAD 11.52 m below the defined Series 2, Stage 3 boundary based on the FAD of *P. subangulata* (Topper, unpubl. data). In summary, this would mean that *J. phaselo*, along with *L. circumbolina*, first appear during Terreneuvian, Stage 2 and therefore represent the oldest known bivalved arthropods from Cambrian East Gondwana.

4.Methods & Terminology

Bradoriid soft parts are rarely preserved and therefore their taxonomy is necessarily based on features of the shield (Hou et al., 2002). Bradoriids may be acid leached from the surrounding matrix or examined as ‘crack-out’ specimens on bedding planes. Acid leached specimens have a tendency to preserve microstructures in finer detail than crack-out specimens and are therefore well suited for taxonomic investigation (Zhang, 2007; Topper et

al., 2011). Material for this study was leached in weak acetic acid (10%), the residues washed, dried and examined using a stereo binocular microscope. Selected specimens were mounted on stubs, gold sputter coated and imaged using a JEOL JSM-6480LA Analytical Scanning Electron Microscope. Descriptive terms used herein follow Siveter and Williams (1997), Williams and Siveter (1998), Hou et al. (2002) and Topper et al. (2011).

5. Systematic Palaeontology

Figured material has been allocated SAM P numbers and is lodged in the South Australian Museum (palaeontological collections).

Phylum Arthropoda Siebold and Stannius, 1845

Order Bradoriida Raymond, 1935

Family Comptalutidae Öpik, 1968

Jiucunella Hou and Bergstrom, 1991

Type species. Jiucunella paulula Hou and Bergström, 1991 from the lower Cambrian Qiongzhusi Formation, Chengjiang County, Yunnan Province (Maotianshan section).

Jiucunella phaselo sp. nov. (Fig. 3A-M)

Type material. The Moro Section (and spot localities) yielded 242 individual valves of *Jiucunella phaselo* (Table 1), including six with conjoined shields. Most specimens from the Moro Section are from the Wilkawillina Limestone (Winnitunny Creek Member), the richest horizons within the section are 866.0 (668.71 m true thickness) and 881.6 (681.0 m true

thickness). Two valves also occur within the Hideaway Well Member at 534.1 m and 564.5 m true thickness. A spot locality to the north of the section, also in the Wilkawillina Limestone (Spot Locality D; 30° 43.316'S; 139° 11.990'E) is also very rich. The holotype (SAM P48652; Fig. 3E, H, J) with conjoined valves is derived from horizon 881.6 (681.0 m true thickness). Paratypes: Fig 3A, L (SAM P48648), B (SAM P48649), C (SAM P48650), D (SAM P48651), F, M (SAM P48653), G, K (SAM P48654) and I (SAM P48655) are from horizon 881.6 (Winnitunny Member of the Wilkawillina Limestone). Figure 3G is derived from horizon 844.0 (Winnitunny Creek Member, Wilkawillina Limestone). Unfigured paratypes include an additional 233 individual valves and two conjoined specimens.

Etymology. From the Greek '*phaselos*' meaning kidney-bean, in reference to the bean-shaped lobe in the anterodorsal region of the shield.

Diagnosis. Strongly postplete, straight hinge line. Anterior cardinal corner spicate. Posterior cardinal corner less acute. Weak rim present with continuous shallow groove between cardinal corners. Single, prominent bean-shaped lobe at the anterior with weak or no sulcus to the posterior. Remainder of carapace smooth. Coarse punctae visible internally.

Occurrence. Hideaway Well and Winnitunny Creek Members of the Wilkawillina Limestone, Arrowie Syncline, Flinders Ranges, South Australia; Terreneuvian, Stage 2.

Description. Strongly postplete, hinge line straight or with very weak anterodorsal cusp. Anterior cardinal spine tapers more sharply than posterior spine. Anterior cardinal spine joins rounded anteroventral margin. Posterior cardinal corner joins concave posterodorsal margin. Spine variably present on posterodorsal curve (Fig. 3A, G, L). Ventral margin straight.

Posterodorsal margin strongly curved. Single, elongated, bean-shaped lobe occurs at anterior, curve mirroring shape of anteroventral margin. Sulcus behind lobe very weak or absent. Shield smooth. Narrow, lip-like rim continuous between cardinal corners, thickening toward the posterior. Groove separates rim from main part of shield. Shield smooth externally, punctae visible internally (Fig. 3M). Shields close snugly with no ventral gape (Fig. 3G and K).

Remarks. Shield outline is characteristic of the comptalutids with a straight hinge line, and acute angles at both cardinal corners and the posterodorsal and anterodorsal curves.

Jiucunella phaseola sp. nov. is strongly postplete with a ridge that is entire between the cardinal corners. Lobation is concentrated at the anterior, and external ornament is smooth with coarse punctae visible internally. Comptalutids often bear pronounced sulci behind the anterior lobation, but *J. phaseola* shows none or only a very weak sulcus behind the anterodorsal lobe, and very occasionally shows evidence for a weak dorsal cusp (Fig. 3B).

Jiucunella phaseola is similar to the comptalutids *Comptaluta* Lee, 1975, and *Alutella* Kobayashi and Kato, 1951. However, while these bradoriid taxa have prominent anterodorsal lobation, they also feature strong sulci separating lobes from the inflated shields. *Jiucunella phaseola* most strongly resembles the type species, *Jiucunella paulula* Hou and Bergström, 1991, from the lower Cambrian Qiongzhusi Formation, Chengjiang County, Yunnan Province, South China in that it is non-sulcate, with a smooth shield and a single lobe (Hou et al., 2002, p. 388, fig. 21). They differ in that the lobation in *J. phaseola* is concentrated in the anterior, rather than toward the ventral part of the shield. In addition, the lobe is bean-shaped with rounded ends and does not taper as in *J. paulula*. *Jiucunella paulula* also features a wide lateroadmarginal ridge, whereas *J. phaseola* has a more lip-like rim.

*Jiucunella phaselo*a shields are well preserved and feature a suite of finely preserved details. The texture of the carapace is noteworthy and demonstrates the level of detail that can be revealed by acid-leaching techniques. The texture of the shields shows that they were made of recalcitrant organic material or only very lightly mineralised. The outer layer of the carapace is often dented and folded in many places, and appears to have been relatively flexible. In the holotype, soft circular features occur around the anterior node (Fig. 3J). These are not present in other specimens and thus are likely to be preservational artefacts.

The Moro specimens exhibit a distinct layering of the carapace, particularly in areas that have been damaged (Fig. 3G, K). In some cases much of the outer layer has been effaced, with the remaining outer layer showing evidence of abrasion. This indicates that accurate description of carapace texture can often be problematic, with descriptions of degraded specimens possibly erroneous (see also Siveter and Williams 1997). Nevertheless, in this case comparison between highly abundant specimens has permitted the establishment of the standard suite of features present in this taxon.

Phasoia Hinz-Schallreuter, 1993

Type species. Ophiosema spicatum Öpik, 1968. Middle Cambrian Yelvertoft Beds, Queensland, Australia.

Remarks. This genus was originally named *Ophiosema* by Öpik (1968) which was a homonym of a lepidopteran genus. *Phasoia* was proposed by Hinz-Schallreuter (1993) as a replacement.

Phasoia cf. *spicata* (Öpik, 1968) (Fig. 4A-I)

349

350 *Material.* Ten damaged individual shields and several fragments with a similar
351 microornament. All specimens were retrieved from a single stratigraphic horizon, Moro
352 1043.0, located 809.76 m true thickness above the base of the section, in the Wirrapowie
353 Limestone (Table 1), Fig. 4A, G (SAM P48656), B (SAM P48657), C, H, I (SAM P48658),
354 D (SAM P48659), E, F (SAM P48660). Unfigured specimens include a further five poorly
355 preserved shield fragments.

357 *Occurrence.* Wirrapowie Limestone, Arrowie Syncline, Flinders Ranges, South Australia;
358 Cambrian Series 2, Stage 3.

360 *Description.* Most complete specimen displays a straight hinge line (Fig. 4A). Most parts of
361 the rim generally broken away. Distinctive open, looping ridge remains intact. Loop sub-
362 circular, running from anterodorsal region around free margin, toward centrodorsal region
363 and terminating posterior of the anterodorsal sulcus (Fig. 4C). Internally, loop presents as a
364 continuous trough in carapace with angular corners near hinge zone (Fig. 4A, B).
365 Microornament consists of fine, nested pustules (approximately 5 μm in diameter; Fig. 4H
366 and I). Pustulation reduced over loop ridge.

368 *Remarks.* The only other bradoriid family to feature prominent, curved continuous ridges that
369 join the anterior and posterior nodes is the Hipponicharionidae. Phasoiids are unique
370 however, in having a ridge that connects the nodes and loops in an almost complete circle.

371 Phasoiids from the Moro section are poorly preserved with margins rarely intact. A
372 single specimen (Fig. 4A) shows an oblique posterior cardinal corner, as seen in the material
373 of *Phasoia* described by Öpik (1968) and Hinz-Schallreuter (1999). This specimen also

shows evidence for a spine at the posterior margin, a feature that has not been previously described (all previous examples of the taxon are crack-out specimens). The looped continuous ridge is particularly distinctive and allows confident assignment of these specimens to *Phasoia*. Of the two species within the genus, the Moro specimens most closely resemble *P. spicata* originally described from the middle Cambrian of the Mt. Isa region in Queensland, which features a similar sub-circular, continuous, open loop (Hinz-Schallreuter et al., 1999, pl. 2, figs 1, 3). This is in contrast to the loop on the shield of *P. rogerensis*, which is interrupted at the ventral area, then continues toward the posterior, terminating at the dorsoposterior corner of the shield (Hinz-Schallreuter et al., 1999, pl. 2, fig. 2).

There is a notable stratigraphic disjunction between the phasoiids recovered from the Moro section (Cambrian Series 2, Stage 3) and previously described material (Middle Cambrian). This implies either that this taxon has a very long stratigraphic range or that the Moro material represents a new taxon. Lack of adequately preserved early Cambrian material precludes erection of a new species and as such this material is compared with reservation to *Phasoia spicata*.

Family Hipponicharionidae Sylvester-Bradley, 1961

Neokunmingella Zhang, 1974

Type species. Neokunmingella minuta Zhang, 1974. Lower Cambrian (Canglangpu Formation). Shijiangjung section, Wuding, Yunnan, south China.

Neokunmingella moroensis sp. nov. (Fig. 5A-O)

Type material. Twelve specimens, mostly derived from a spot locality in the Winnitunny Creek Member (Wilkawillina Limestone) ~370 m along strike (north) of the Moro Section (Spot Locality D; 30° 43.316'E/139° 11.990'S). Additional specimens were collected from the Moro section line at horizon 836.7 (643.0 m above the base of the section; Winnitunny Creek Member, Wilkawillina Limestone), and 1043.0 (809.7 m above the base of the section; Wirrapowie Limestone) (Table 1). Holotype Fig. 5G, M (SAM P48667) and paratypes Fig. 5A (SAM P48661), B (SAM P48662), C (SAM P48663), D (SAM P48664), E (SAM P48665), F (SAM P48666), and K (SAM P48670) are derived from Spot Locality D in the Winnitunny Creek Member of the Wilkawillina Limestone. Paratypes Fig. 5H, J, N (SAM P48668) and I, O (SAM P48669) come from horizon 836.7 in the Winnitunny Creek Member, Wilkawillina Limestone. Unfigured paratypes include a further two fragmentary shields from Spot Locality D in the Winnitunny Creek Member of the Wilkawillina Limestone.

Etymology. Named after Moro Gorge, a site of cultural significance to the Adnyamathana People of Nepabunna, located 6 km north of the Moro section (Fig. 1).

Diagnosis. Outline postplete with confluent U-shaped lobation. Lobation variably emphasised at anterior and posterior. Straight hinge line. Weakly defined central node is irregularly shaped, tilts from hinge line toward anterior. Short spine projects from posterodorsal curve. Microornament present as scales or micro-scale polygons with centrally located raised lumps.

Occurrence. Wilkawillina Limestone and Wirrapowie Limestone, Arrowie Syncline, Flinders Ranges, South Australia; Cambrian Series 2, Stage 3.

Description. Postplete shield with smooth, rounded rim around posteroventral margin. Dorsal margin straight. Anterior cardinal corner tapering at acute angle. Posterior cardinal corner oblique. Posterodorsal margin concave. Short spine on posterodorsal curve (Fig. 5B, G and M). Complete shields range from approximately 1100 to 1400 μm in length. Confluent anterior and posterior lobation forms a U-shape ridge that follows shape of free margin; centre of shield depressed. Lateroadmarginal rim narrow and smooth, with a broad flat area between rim and posterior lobe at posterior curve. Small, irregularly shaped central node present close to hinge, inclined at an angle to dorsal margin. Microornament variable; may be present as a fine, polygonal network with small raised lumps in centre of each polygon. Each discrete polygon is approximately 5 μm in diameter (Fig. 5O). Microornament may also consist of scale like lumps (approximately 5 μm in diameter) (Fig. 5M). Development of microornament varies over shield.

Remarks. Neokunmingellids exhibit all the classic features of the Hipponicharionidae including a postplete shield, subtriangular outline; confluent lobation and granulose microornament. The Moro specimens exhibit distinctive neokunminellid features such as confluent anterior and posterior lobes, amplete to postplete shield and a sub-ovate node sub-parallel with the dorsal margin (Hou et al., 2002, p. 398, fig. 24 a-l).

The Moro specimens display a distinctive polygonal and scaly microornament that was not noted in Chinese specimens of *Neokunmingella minuta* by Zhang (1974) or *Neokunmingella* cf. *minuta* by Hou et al. (2002), probably because fine details of ornament are rarely preserved in crack-out specimens. Microornament on the shield of *Neokunmingella shuensis* Zhang 2007 consists of a combination of pitting and low pustules (Zhang, 2007, pl. 19, figs 1-15), unlike that on *Neokunmingella moroensis*. Development of the ornament is variable and occasionally appears distinctly more pustulose than reticulate (Fig. 5M).

Variability in microornament was also documented in *Albrunnicola bengtsoni* from lower Cambrian glacial erratics from King George Island, Antarctica by Wrona (2009). These specimens display great variation in preservation and demonstrate that the true external microornament is often exfoliated, leaving behind a ‘false’ microornament on underlying layers consisting of a series of lumps or scales (Wrona 2009, p. 359, fig. 7a-d). These are similar to the pustules present in some of the Moro specimens (Fig. 5K, M). Such differences between individuals are likely the result of differential preservation and abrasion.

A single (fragmentary) shield from the Moro Section (Fig. 5H) has a U-shaped ridge giving the impression that this specimen is more amplete than other specimens. However, this specimen also displays the polygonal microornament (Fig. 5O) that links it to the postplete individuals. Shield breakage at the anterior margin makes it difficult to clearly establish an amplete outline for this specimen. The anterior and posterior lobes of the specimens derived from the Moro section also vary in development. Most are clearly confluent, creating the U-shaped ridge (Fig. 5A, E, F), while in others the lobes are more isolated and ‘pinch-out’ toward the ventral margin (Fig. 5C, G, H). The U-shaped ridge is still visible in these individuals, though it is weakly developed. Similar lobe and ridge variation is also documented in *Neokunmingella shuensis* Zhang, 2007 (pl. 19, figs 1-11) from the lower Cambrian Yu’anshan Formation in South China. However, *N. moroensis* has a uniformly curved, semi-circular outline (Fig. 5A-H) which differs from the postplete, sub-triangular outline in *N. shuensis*. Additionally, none of the specimens derived from acid processing figured by Zhang (2007) from the lower Cambrian of China display the characteristic polygonal microornament of *N. moroensis*. Furthermore, neither *N. minuta* nor *N. shuensis* display a short spine at the posterodorsal curve as in *N. moroensis*.

Hou et al. (2002) described the central node in specimens of *N. cf. minuta* as having variable size and shape. All Moro specimens display a similar node that also varies in shape

and prominence. The node is inclined to the hinge line, consistently tilted toward the anterior. The variability in the shape and size of these nodes may also represent intraspecific variation attributed to ontogenetic changes or sexual dimorphism.

Family ?Bradoriidae Matthew, 1902

Remarks. *Sinskolutella* was originally assigned to the Alutidae (Melnikova, 1998), a family which grouped together bradoriids with a border around the free margin of the shield (Shu and Chen, 1994). Grouping bradoriids in this way is now considered taxonomically insignificant and the taxonomic name ‘*Aluta*’ is now regarded as a *nomen dubium* (Shu and Chen, 1994).

Family level attribution of the genus is difficult due to the presence of a combination of characters that occur in a wide range of family groups, and uncertainty regarding the taxonomic significance of valve size, shape, lobation and ornament. *Sinskolutella cuspidata* sp. nov. is non-lobate and features a distinctive dactilosopic, fingerprint-like microornament which allies it with the Bradoriidae Matthew, 1902. However, the Bradoriidae are generally larger, reaching lengths of 6 – 7 mm (Siveter and Williams 1997). Additionally, the type species of *Sinskolutella* Melnikova, *S. ordinata* has a maximum length of up to 8.0 mm while the length of the new species does not exceed 2.0 mm. The Bradoriidae generally have a straight hinge (Siveter and Williams 1997), whereas *Sinskolutella* often has a prominent dorsal cusp (Fig. 6A-C, E, I, J, L; Melnikova 1998, pl. 2, figs 1, 2).

The presence of the dorsal cusp, in addition to the postplete outline, valve dimensions and finely textured microornament in *Sinskolutella cuspidata* sp. nov. could also point to a relationship with the Kunmingellidae. However, kunmingellids feature prominent anterior and posterior lobation which is not present in *S. cuspidata*. Cambriids are also similar to *S.*

cuspidata in that they feature a similar dorsal cusp. However, cambriids may also be lobate and are much larger than the Moro specimens, with a diagnostic size range between 6.0 and 17.5 mm in length (Hinz-Schallreuter et al. 2007). In addition, cambriids while occasionally bearing granulose microornament, do not feature dactiloscopic microornament. Assignment to the Bradoriidae is tentative due to the combination of character states in the new taxon.

Sinskolutella Melnikova, 1998

Type species. Bradoria ordinata Melnikova, 1983. Cambrian Series 2, Stages 3-4 (Botoman) of the Siberian Platform (Sinskoe Formation).

Emended diagnosis (after Melnikova, 1998, p. 359). Shield postplete, strongly convex with strong hinge line and dorsal cusp. Sharp anterodorsal curve; posterodorsal curve of margin at right angles to obtuse. Shield with pronounced posterior curve projecting past posterodorsal curve. Free margin bears smooth, flattened rim. Microornament on main part of shield pulvinate or dactiloscopic.

Remarks. Previously published work describes *Sinskolutella* as having a straight hinge line (Melnikova, 1998), but the emended diagnosis recognises the fact that a distinct dorsal cusp is apparent in the crack-out specimens illustrated by Melnikova (1998, pl. 2, figs 1, 2). The microornament consists of a fingerprint-like, dactiloscopic pattern (Fig. 6D, G, N), and the shields are non-lobate and strongly convex, indicating that the Moro specimens belong to *Sinskolutella*.

Sinskolutella cuspidata sp. nov. (Fig. 6A-O)

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2 525 *Type material.* The Moro section yielded 223 specimens. These most often occur as
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5 526 individual shields, though some are conjoined. *Sinskolutella cuspidata* is most abundant at
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7 527 horizon 1081.0 where the end of the section has been offset by 90 m towards the north-
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10 528 northeast (839.7 m true thickness above the base of the section – see Table 1). *Sinskolutella*
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12 529 *cuspidata* outnumbered all other taxa (100+ specimens) at this horizon in the Wirrapowie
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14 530 Limestone. *Sinskolutella cuspidata* is also Limestone Formation), and 893.0 (690.0 m above
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17 531 the base of the section; Winnitunny Creek Member of the Wilkawillina Limestone) (Table 1).
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19 532 Holotype Fig. 6C (SAM P48673) from horizon 933.2 (Wirrapowie Limestone). Paratypes
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22 533 Fig. 6A, M (SAM P48671), B (SAM P48672), I (SAM P48679), J (SAM P48680) and L
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24 534 (SAM P48682) from horizon 1081.0 where the section has been offset, Wirrapowie
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27 535 Limestone. Paratypes Fig. 6 D (SAM P48674) E, O (SAM P48675) F (SAM P48676), G, N
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29 536 (SAM P48677) and H (SAM P 48678) from horizon 933.2, also in the Wirrapowie
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32 537 Limestone. Additional unfigured paratypes include 210 separated valves and a seven
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34 538 conjoined specimens.

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39 540 *Occurrence.* Wilkawillina Limestone and Wirrapowie Limestone, Flinders Ranges, Arrowie
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41 541 Syncline, South Australia; Cambrian Series 2, Stage 3.

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46 543 *Etymology.* From the Latin ‘*cuspidatus*’ meaning pointed, for the sharp dorsal cusp and spine
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49 544 at the posterodorsal curve.

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53 546 *Diagnosis.* Shield postplete, rounded, with pronounced convexity at posterior margin which
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56 547 extends past posterior cardinal corner. Sharp dorsal cusp located immediately anterior of
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58 548 central part of hinge line. Non-lobate. Rim flattened, smooth, continuous between cardinal
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corners, somewhat thicker around curved ventral-posterior part of shield. Small spine at posterior curve. Microornament dactiloscopic formed by series of micron scale pulvinate mounds. Total length of shield does not exceed 2 mm.

Description. Outline postplete, valves inflated, free margin strongly curved. Dorsal margin bearing pronounced anterodorsal cusp. Lateroadmarginal rim well developed; smooth, flat, entire between cardinal corners, thickest and most strongly curved at posteroventral margin. Posterior cardinal corner oblique, with anterior cardinal corner tapering to a short spine. Short spine also on posterodorsal curve of each shield. Shield non-lobate with very weak anterodorsal sulcus. Microornament over shield micro-pulvinate (Fig. 6D, G) consisting of pillow-like mounds ~20-30 μm across, surrounded by smaller mounds ~5 μm across (Fig. 6N). Internally, coarse punctae visible (Fig. 6O). Shields do not exceed 2 mm in length.

Remarks. The Moro specimens strongly resemble *S. concentrisulcata* as described and illustrated by Melnikova (1998, pl. 2, figs 9-11) from the lower Cambrian of Siberia. However, the short spine on the posterodorsal curve in *S. cuspidata* is not present in *S. concentrisulcata*, nor the similar taxon *Bradoria scrutator* Matthew, 1899. *Bradoria scrutator* has a similar dactiloscopic ornament to *S. cuspidata* (Siveter and Williams, 1997, pl. 1, figs 1-14), but this species features a smooth, circular node at the anterodorsal margin and lacks a dorsal cusp. Other genera featuring similar fingerprint-like microornament include *Walcottella* Ulrich and Bassler, 1931 and *Indiana* Matthew, 1902. However, *Walcottella* features an anteroventral and weak dorsal node, and *Indiana* does not have an admarginal rim (Siveter and Williams 1997).

A crack-out specimen of *Matthoria?* sp. described by Vannier et al. (2005) from the lower Cambrian Pardailhan Formation, southern France is considerably larger than *S.*

cuspidata (4 mm), though closely resembles the Moro specimens since it also has a strong dorsal cusp and weak lobation. This taxon is described as lacking surface ornament, though comparing ornament between crack out and acid etched specimens is complicated by the fact that even the well preserved external microornament in some Moro specimens is prone to peel away and leave a smooth surface (Fig. 6A, B, M).

Sinskolutella cuspidata is generally well preserved, often with shields strongly conjoined (Fig. 6F, H, K). The shape of the lateral outline and width of the marginal rim displays intraspecific variation; some specimens show little evidence of a wide rim (e.g. Fig. 6D, F). The external ornament also appears to be prone to exfoliation, often revealing a smooth layer underneath. In this regard there are a few specimens (Fig. 6A) with a well developed marginal rim but which lack strong dactilosopic ornament. Differential damage to the margin and the shedding of the distinctive ornament has implications for accurate identification and taxonomic comparisons, especially between crack-out and acid derived material. The Moro material emphasises that significant taxonomic details may be missing even in specimens that appear relatively well preserved.

Family Haoiidae Shu, 1990

Jixinlingella Lee, 1975

Type species. Jixinlingella clithrocosta Lee, 1975. Lower Cambrian Shuijingruo Formation, Shaanxi, central China.

Emended diagnosis (after Zhang, 2007, p. 136). Postplete shield, less than 2 mm in length.

Prominent reticulate (hexagonal) ornament of raised coarse ridges over shield. Inflated

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599 anterior lobe connected via curved submedian ridge to submedian node. Well developed
600 anterior sulcus. Subdorsal swelling variably developed. Marginal groove separating marginal
601 spinose frill from main valve. Duplicature well developed.

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603 *Remarks.* The Haoiidae consists of two genera characterised by a prominent network of
604 coarse interconnected raised ridges forming a distinctive reticulation over the surface of the
605 valves. These ridges form hexagonal, honeycomb-like patterns (Fig. 7) or long dorso-ventral
606 ridges traversing the shield (Shu, 1990, pl. 1, figs 1-6, 9; Zhang, 2007, pl. 14m, figs 9-14).
607 Zhang (2007, p. 136) noted the close similarity between *Haoia* and *Jixinlingella* but
608 suggested these taxa can be discriminated based on a more complex reticulation, a broad
609 anterior lobe and a well-developed marginal rim with frill. *Haoia* is characterised by having
610 fewer, larger and more elongate polygonal fossae in the central region of the shield and lacks
611 a marginal frill (Shu, 1990, pl. 1, figs 1-6, 9). *Jixinlingella*, in contrast, has a well-developed
612 marginal frill and smaller, more uniformly spaced polygonal reticulation (Fig. 7A-N; Zhang
613 2007, pl. 14, figs 9-14). The carapace of *Jixinlingella daimonikoa* sp. nov. is postplete, with a
614 well-developed anterior sulcus, marginal groove and frilled rim (Fig. 7A). These features in
615 combination with the coarse, reticulate network of ridges suggest that the new taxon is
616 congeneric with *Jixinlingella*.

617 Shu (1990) also erected the new taxon, *Eotuzoia minima* Shu, 1990, based on
618 fragmentary material, but did not assign it to a family. The specimens feature coarse,
619 honeycomb reticulation that suggests *Eotuzoia* belongs to the Haoiidae. Skovsted et al. (2006,
620 p. 32, fig. 13A) described a poorly preserved conjoined specimen from the Third Plain Creek
621 Member of the Mernmerna Formation (*Pararaia bunyeroensis* Zone) as *Haoia* cf.
622 *shaanxiensis*. This specimen has centrally located elongate geometric fossae characteristic of

Haoia shaanxiensis. This broken specimen also appears to lack a marginal frill seen in both *J. clithrocosta* and *J. daimonikoa*.

Jixinlingella daimonikoa sp. nov. (Fig. 7A-N)

Type material. Holotype (SAM P 48683) has conjoined valves (Fig. 7A, C, L) from horizon 1043.0, Wirrapowie Limestone, lower Cambrian of the Flinders Ranges, South Australia. This is supplemented by nine unfigured and nine figured paratypes (Fig. 7B, J, K [SAM P48684], D [SAM P48685], E [SAM P48686], F [SAM P48687], G [SAM P48688], H [SAM P48689], I [SAM P48690], M [SAM P48691], N [SAM P48692]) in the form of isolated shields and one conjoined specimen from horizons 893.0 (690.0 m true thickness above the base of the section), 881.6 (681.0 m true thickness above the base of the section), 866.0 (668.7 m true thickness above the base of the section) in the Winnitiny Creek Member of the Wilkawillina Limestone and 1081.0 (839.7 m true thickness above the base of the section) in the Wirrapowie Limestone (Table 1).

Etymology. From the Greek ‘*Daimonikos*’ meaning of demons, for the paired, horn-like spines on the posterodorsal margin of the carapace.

Diagnosis. Postplete with coarse hexagonal to pentagonal network of polygonal ridges forming uniform reticulation over shield. Anterior and posterior cardinal spines present. Anterior sulcus broad and smooth. Subdorsal swelling absent. Marginal furrow present with frilled rim. Spine pair on posterodorsal margins of carapace.

647 *Occurrence.* Winnitunny Creek Member of the Wilkawillina Limestone and Wirrapowie
648 Limestone, Arrowie Syncline, Flinders Ranges, South Australia; Cambrian Series 2, Stage 3.

649
650 *Description.* Shield postplete, with anterodorsal cusp. Anterior and posterior cardinal corners
651 tapering to spines. Prominent anterior cardinal spine joins straight anteroventral margin.
652 Weaker posterior cardinal spine joins concave posterodorsal margin. Ventral margin straight.
653 Posteroventral margin strongly curved. Coarse, geometric, reticulate network of ridges
654 defining hexagonal and pentagonal fossae approximately 200-250 μm across, strongly
655 developed over central part of shield. Smaller pentagonal fossae developed closer to margins.
656 Anterior sulcus broad and smooth. Subdorsal swelling absent. Anterodorsal node elongate.
657 Some specimens display a small swelling with a distinctive dorso-ventral cleft situated
658 behind the anterodorsal node (Fig. 7J). Reticulate network interconnects nodes and ridges.
659 Marginal furrow separates valve from frilled rim with short, stubby regularly spaced
660 (mean 40 μm) spines along free margin; absent from posterodorsal margin. Frill particularly
661 well-developed around posteroventral margin, where shield lobation is most prevalent (Fig.
662 7C, L). Posterodorsal shield margin features small tapering, hollow horn-like spine (Fig. 7A,
663 L). Weakly pustulose microornament in fossae, absent from ridge crests (Fig. 7K).
664 Duplicature well developed (Fig. 7E, F). Internally, reticulate ornament presents as deep
665 furrows (Fig. 7E).

666
667 *Remarks.* *Jixinlingella daimonikoa* differs from the type species *J. clithrocosta* from the
668 lower Cambrian Shuijiangtuo Formation of South China (Lee, 1975) as it has more regular
669 geometric reticulation defining hexagonal and pentagonal fossae. Additional features that
670 distinguish *J. daimonikoa* from the type species are the presence of an anterodorsal cusp,

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671 anterior and posterior cardinal spines and a distinctive pair of posterodorsal spines at the free
672 margin (Fig. 7A, C, L). The subdorsal swelling in *J. clithrocosta* is absent in *J. daimonikoa*.

673 *Eotuzoia minima* has a similar geometric reticulate ornament to *J. daimonikoa*, but it
674 is continuous over the majority of the carapace, including the area occupied by the sulcus in
675 *J. daimonikoa* (Shu, 1990, fig. 43). The hand drawn illustration of *E. minima* indicates a more
676 ample outline and shows no evidence of an anterodorsal cusp. Additionally, there is no
677 evidence for a frilled margin or a posterodorsal spine in *E. minima*.

678
679 Family Mongolitubulidae Topper, Skovsted, Harper and Ahlberg, 2013b

680
681 *Mongolitubulus* Missarzhevsky, 1977

682
683 *Type species. Mongolitubulus squamifer* Missarzhevsky, 1977. Early Cambrian of Mongolia.

684
685 *Remarks.* Within this genus, six species are currently recognised: *Mongolitubulus squamifer*
686 Missarzhevsky, 1977, *M. henriksen* Skovsted and Peel, 2001, *M. unispinosa* Topper,
687 Skovsted, Brock and Paterson, 2007, *M. unialata* (Zhang, 2007), *M. reticulatus* Kouchinsky,
688 Bengtson, Clausen, Gubanov, Malinky and Peel, 2011 and *M. aspermachaera* Topper,
689 Skovsted, Harper and Ahlberg, 2013b. Spines of *Mongolitubulus* are often found in isolation,
690 and in the past the affinities of these fossils have been problematic with suggestions of their
691 affinities ranging from protoconodonts (Missarzhevsky, 1977) to hyolithelminths (Rozanov,
692 1986) and lobopodians (Dzik, 2003). Similarly ornamented spines may also be convergent
693 among diverse taxa, for example trilobite spines have been shown to have similar ornament
694 to *Mongolitubulus* (Li et al., 2012).

Skovsted and Peel (2001) suggested that *Mongolitubulus* spines projected from the shields of bradoriid arthropods and this has been demonstrated with the discovery of *M. henrikseni*, *M. unispinosa* and *M. unialata* with intact spines (Skovsted, 2005; Topper et al., 2007; Zhang, 2007). Similar spine and shield relationships have not yet been confirmed for the type species, *M. squamifer*. *Mongolitubulus unispinosa* from the Mernmerna Formation in the Donkey Bore Syncline has a single spine, at least as long as the hinge line, attached to the central portion of the shield (Topper et al., 2007, fig. 6A, B). In *M. unialata* from the lower Cambrian of China, a similarly long spine is attached to the anterior part of the valve (Zhang 2007, pl. 17, figs 1-7). The Cambrian Series 3 Stage 5 species *M. reticulatis* also hosted a single, elongate spine, but the position of the spine on the shield has not been confirmed (Kouchinsky et al., 2011). The strong microstructural similarities between the spines of *M. squamifer* and bradoriid shields provides convincing evidence for a bradoriid arthropod affinity for the type species (Topper et al., 2013b). Specimens of the new species *M. anthelios* from the Moro section also include conjoined spines and shields, confirming their bradoriid origin (Fig. 8B, H).

The function of the spine in *Mongolitubulus* remains enigmatic. During life, the spines would have protruded at an acute angle from the shields, and doubtless had an effect on locomotion. The presence of such extravagant spines would not appear to be conducive for burrowing or free swimming. The spines may have been a defensive mechanism to deter predators, particularly in taxa such as *M. henrikseni* which had shields encrusted with a number of spines of variable shapes and sizes (Skovsted, 2005).

Mongolitubulus anthelios sp. nov. (Fig. 8A-Q)

Type material. Twenty-three *Mongolitubulus anthelios* specimens have been extracted from the Moro section. Eleven of these are individual spines, four are shields with the spine broken, five are shields with the spine intact and three are crushed, mostly complete individuals. Majority of *M. anthelios* specimens were recovered from horizons 866.0, 881.6 and 889.0, corresponding to 668.71 m, 681.0 m and 687.62 m true thickness above the base of the section, respectively (Winnitunny Creek Member, Wilkawillina Limestone). Additional localities include 918.5 (711.6 m true thickness above the base of the section, Wirrapowie Limestone), horizon 855.3 (660.3 m true thickness from the base, Winnitunny Creek Member, Wilkawillina Limestone) and a spot locality along strike to the north of the section, (Spot Locality Ab; 30° 43.474'E/139° 12.094'S) (Table 1). Holotype Fig. 8H, L (SAM P48700), and paratypes Fig. 8A, N, O (SAM P48693), B (SAM P48694), C (SAM P48695), D (SAM P48696), E, J (SAM P48697), F (SAM P48698), G, K (SAM P48699), I (SAM P48701), M (SAM P48702), P (SAM P48703), Q (SAM P48704) Additional unfigured paratypes include four individual spines, three damaged shields with intact spines, three damaged shields with the spine broken and one crushed individual.

Etymology. From the Greek '*anthelion*' meaning a tuft or plume of a reed, in reference to the tufted arrangement of the scales on the tip of the spines.

Occurrence. Winnitunny Creek Member of the Wilkawillina Limestone and Wirrapowie Limestone, Arrowie Syncline, Flinders Ranges, South Australia; Cambrian Series 2, Stage 3.

Diagnosis. Single spine emerging from centre of convex shield. Spines hollow, gently arched, tapering to a sharp point. Two sizes of scales on spines - dispersed, larger rhomboid scales (~25 um long) surrounded by more numerous smaller (~5 um), stubby scales or bumps. All

scales form a loosely imbricating pattern. Shield displays toothed ornament around free margin. Shield texture smooth.

Description. Shield strongly convex, single spine occurring at centre of shield. Spine hollow, approximately 100 µm diameter at base, gently arched and apically tapering to a sharp point. Longest spines over 1 mm in length. Scale ornament well developed on spine. Two sizes of scales; larger rhomboid, occasionally spinose scales (max. length ~50 µm) surrounded by smaller low tubercles or bumps (Fig. 8E, F, G, J, K). Larger scales occasionally with twinned tips (Fig. 8K). Distribution of ornament along spines is variable. Some spines remain smooth close to carapace with ornament developing about a third to a quarter along the spine (Fig. 8E-G). Other spines display ornament over nearly entire surface. Free margin of valve ornamented by small teeth spaced at regular (~50 µm) intervals (Fig. 8A, C, L). External microtexture of valve smooth.

Remarks. *Mongolitubulus anthelios* spines feature a unique pattern of two different sized scales – larger rhomb-shaped, occasionally tapering scales interspersed with many low, bump-like scales. Ornament becomes more established toward the distal end with the tips having slightly more elongate scales that make the spine appear ‘feathery’. Isolated spines share identical microornament and can be confidently assigned to *M. anthelios*.

The central location of spine attachment to the shield in *M. anthelios* is similar to that in *M. unispinosa* from the Mernmerna Formation in South Australia. However, *M. unispinosa* is characterised by spines with a uniformly distributed pustulose microornament (Topper et al., 2007, fig. 6C-J). The spines of *M. henrikseni* exhibit an ornament of similarly sized, imbricate, well-spaced, blunt scales. The heavily ornamented shields of *M. henrikseni* also

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768 have shorter spines concentrated around the rim and larger spines extending from the central
769 part of the shield (Skovsted and Peel 2001., fig. 4A, B, D-F).

770 The scales on *M. anthelios* spines are also unlike the scales of *M. squamifer* which
771 usually exhibit regularly spaced, uniformly sized, diamond-shaped scales over the length of
772 the spine. *Mongolitubulus anthelios* spines also do not exhibit the same hooked tip as seen in
773 many specimens of *M. squamifer* (Topper et al., 2007, fig. 5A-K, M, N) or *M. unispinosa*
774 which are thorn-like and often recurved (Topper et al., 2007, fig. 6A, J) . The shield of *M.*
775 *unispinosa* is smooth to pustulose with no ornament around the rim unlike the frilled rim in
776 *M. anthelios*.

777 *Mongolitubulus anthelios* can also be distinguished from other taxa by the finely
778 toothed frill on the rim of the shield. The toothed, frilled rim distinguishes *M. anthelios* from
779 *M. aspermachaera* described from the Furongian of Sweden (Topper et al., 2013b). The
780 shields and spines of the Swedish taxon are also covered in minute, raised subcircular
781 structures and the shield displays a distinct, broad lateroadmarginal ridge (see Topper et al.,
782 2013b, figs 4, 5), morphological features not seen in *M. anthelios*. The shield of *M.*
783 *reticulatus* is smooth like that of *M. anthelios*, though it shows no evidence of an ornamented
784 rim, and the spine in this taxon is not centrally placed.

785 786 **6. Conclusions**

787 Bradoriid faunas from the early Cambrian of South Australia have proven to be highly
788 diverse and abundant (Skovsted et al., 2006; Topper et al., 2007, 2011). The new assemblage
789 described herein consists of six taxa, including five new species, from a variety of bradoriid
790 families including Comptalutidae, Hipponicharionidae, Mongolitubulidae and Haoiidae. The
791 assemblage, like others described from Australia is highly endemic at species level, but
792 shows close biogeographic ties to South China at genus level. This study has demonstrated

that the origin of bradoriids pre-date the incoming of trilobites in the lower Cambrian succession of South Australia, suggesting East Gondwana is a likely centre of origin for the Bradoriida. Along with coeval shelly taxa (such as tommotiids), the documented diversity, abundance and high fidelity preservation of bradoriids from East Gondwana (and South China) have great potential for establishing regional chronostratigraphic stages and series for the lower Cambrian of East Gondwana that should facilitate intercontinental correlation. .

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Figure captions

Fig. 1. Regional locality and detailed geological map showing the study area in the Arrowie Syncline, Flinders Ranges, South Australia. The Moro section was measured through the Wilkawillina Limestone and Wirrapowie Limestone on the eastern limb of the syncline.

Fig. 2. Stratigraphic ranges of bradoriids and key tommotiid, brachiopod and molluscan taxa through the Wilkawillina Limestone and Wirrapowie Limestone in the Moro section. The approximate base of the *Abadiella huoi* biozone is shown at horizon 866.0 (= 668. 7 m true thickness above the base of the section). The stratigraphic range of the micromollusc *P. subangulata* is shown, the FAD of this taxon (dashed line) is used to approximate the base of Cambrian Series 2, Stage 3 (*sensu* Peng et al., 2012). Note the FAD of *Jiucunella phaseloia* occurs 134.6 m below the base of *A. huoi* zone and 47.6 m below the FAD of *P. subangulata* within the biohermal slope facies of the Hideaway Well Member (Wilkawillina Limestone).

Fig. 3. *Jiucunella phaselloa* sp. nov. All figured specimens are from the Winnitunny Creek Member of the Wilkawillina Limestone, except for D, which is from the Hideaway Well Member. A, L, lateral view of right shield with spine preserved at posterior curve, SAM P48648, sample 881.6. B, lateral view of right shield with elongate anterior cardinal spine, SAM P48649, sample 738.0. C, right lateral view of specimen with conjoined shields, anterior node compressed, SAM P48650, sample 881.6. D, lateral view of left shield with damage at margins, SAM P48651, sample 699.5 (Hideaway Well Member). E, H, J, holotype, oblique view, shields conjoined, SAM P48652, sample 881.6. F, M, internal view of right shield showing coarse punctae, SAM P48653, sample 881.6. G, K, oblique view of specimen with tightly closed shields, spine pair visible at posterior curve, SAM P48654, sample 844.0. I, lateral view of right shield, SAM P48655, sample 881.6.

Fig. 4. *Phasolia* cf. *spicata* (Ö pik, 1968), all specimens from the Wirrapowie Limestone in the Moro section, sample 1043.0. A, G, lateral view of left shield with looping ridge, straight hinge and base of hollow spine at posterior, SAM P48656. B, internal view of right shield, margins damaged, loop present internally as a continuous furrow, SAM P48657. C, H, I, lateral view of right shield, ornament consists of nested pustulations, SAM P48658. D, fragmentary shield, looped ridge visible, SAM P48659. E, F, fragmentary shield showing abraded ornament, SAM P48660.

Fig. 5. *Neokunmingella moroensis* sp. nov. A-G, L, M all from Spot Locality D (Wilkawillina Limestone; Winnitunny Creek Member), H, J, N and K from horizon 836.7 (Winnitunny Creek Member, Wilkawillina Limestone), I, O from horizon 1043.0 (Wirrapowie Limestone). A, L, lateral view of left shield, abraded polygonal microornament visible, SAM P48661. B, internal view of right shield showing confluent lobation, SAM P48662. C, anterior fragment

1012 of left shield, with prominent anterior lobation and central node, SAM P48663. D, internal
 1013 view of posterior fragment of left shield, spine at posterior curve, SAM P48664. E, lateral
 1014 view of right shield, SAM P48665. F, lateral view of right shield, SAM P48666. G, M,
 1015 holotype, lateral view of right shield with strong lobation, microornament appears pustulose,
 1016 spine preserved on dorsal-posterior curve, SAM P48667. H, J, N, lateral view of left shield
 1017 with breakage at anterior, shows faint polygonal ornament, sample 836.7 (Wilkawillina
 1018 Limestone; Winnitunny Creek Member), SAM P48668. I, O, fragmentary specimen, posterior
 1019 lobation visible, polygonal ornament well preserved, sample 1043.0 (Wirrapowie Limestone),
 1020 SAM P48669. K, severely abraded right shield, SAM P48670.
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 Fig. 6. *Sinskolutella cuspidata* sp. nov. A, B, I, J, K, L from sample 1081.0 EOS (end of
 section), where the Moro section has been offset ~90 m to the NNE; Wirrapowie Limestone.
 C, D, E, F, G, H from sample 933.2 (Wirrapowie Limestone). A, M, lateral view of left shield
 with rim well preserved, micro-pulvinate ornament has been abraded from central part of
 shield, SAM P48671. B, left lateral view of two shields, separated at hinge, dorsal cusp
 visible, SAM P48672. C, holotype, left shield with spine at posterior curve, SAM P48673. D,
 right shield, rim abraded, showing well-preserved ornament, SAM P48674. E, O, lateral,
 internal view of left shield with coarse punctae visible, SAM P48675. F, right lateral view of
 conjoined shields, SAM P48676. G, N, lateral view of left shield, micro-pulvinate ornament
 well preserved, SAM P48677. H, lateral view of left shield, SAM P48678. I, overlapping,
 separated shields, SAM P48679. J, separated shields, SAM P48680. K, conjoined shields,
 broken through posterior, SAM P48681. L, internal view of right shield with remains of
 broken left valve adhered to hinge, SAM P48682.

Fig. 7. *Jixinlingella daimonikoa* sp. nov. A, C, L, holotype, conjoined shields gape slightly at anterior, frill present around margin, spine pair at posterior curve, SAM P48683, sample 1043.0 (Wirrapowie Limestone). B, J, K, lateral view of left shield with a spine at posterior curve, broad anterior sulcus and cleft in node at anterior, low pustules in depressions between reticulations, SAM P48684, sample 738.0 (Wilkawillina Limestone,; Winnitunny Creek Member). D, right lateral view of abraded articulated valves, SAM P48685, sample 1043.0 (Wirrapowie Limestone). E, internal view of right shield showing reticulate ornament, SAM P48686, sample 1043.0 (Wirrapowie Limestone). F, internal view of duplicature at spine, SAM P48687, sample 1043.0 (Wirrapowie Limestone). G, abraded left shield, SAM P48688, sample 1043.0, (Wirrapowie Limestone). H, abraded left valve, SAM P48689, sample 1081.0, (Wirrapowie Limestone). I, abraded left shield, SAM P48690, sample 1081.0, Wirrapowie Limestone) M, abraded left shield with broad anterior sulcus, SAM P48691, sample 1043.0, (Wirrapowie Limestone). N, lateral view of right shield, SAM P48692, sample 1043.0 (Wirrapowie Limestone).

Fig. 8. *Mongolitubulus anthelios* sp. nov. All specimens from the Winnitunny Creek Member of the Wilkawillina Limestone. A, N, O, abraded shield, marginal frill, hole where spine has broken away, SAM P48693, sample 881.6. B, spine intact, compressed into dented carapace, SAM P48694, sample 881.6. C, compressed shields with base of spine preserved, SAM P48695, sample 889.0. D, proximal end of hollow spine, SAM P48696, sample 866.0. E, J (SAM P48697), F (SAM P48698), G, K (SAM P48699) individual spines, ornament of rhomboid scales and bumps develop toward tip, all from sample 889.0. H, L, holotype, ornamented spine emerging from convex shield, remains of frill present at margin, SAM P48700, sample 881.6. I, proximal part of spine with flared base, SAM P48701, sample 889.0. M, compressed specimen, spines have been folded together, remaining carapace

1060 crushed around base of spines, SAM P48702, sample 889.0. P, spine with flared base, SAM
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2 1061 P48703, sample 855.3. Q, abraded spine, SAM P48704, sample 899.0.
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6 1062 Table 1. Moro Section Bradoriid Counts. NB: '+' = additional fragments, 'Comp' =
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8 1063 Comptalutidae, 'Hippon' = Hipponicharionidae, '?Brad' = ?Bradoriidae, 'Hao' = Haoiidae,
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10 1064 'Mongo' = Mongolitubulidae. See Figure 2 for Spot Locality information.
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Figure

Figure

WILKAWILLINA LIMESTONE

WIRAPORU LIMESTONE

MORO Section

SSF Samples

Approximate base of A. luoi Biozone

Approximate base of Series 2, Stage 3

Parachanna Formation

Top of section coordinates: 30°43.616' S / 139°12.528' E

Base of section coordinates: 30°43.456' S / 139°11.883' E

Stratigraphic units and fossil ranges:

- WILKAWILLINA LIMESTONE:**
 - Wanintery Creek Member (800-700 m)
 - Hideaway Well Member (600-400 m)
 - Mt. Aunell Member (300-200 m)
 - Woodwardina Dolomite (100-0 m)
- Parachanna Formation:**
 - Bioclastic limestone with prominent crystalline horizons (0-100 m)
 - Archaeocyath-crystalloidal biohermal facies (100-200 m)
 - Massive light grey limestone (200-300 m)
 - Stratolitic limestone (300-400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (400-500 m)
 - Archeocyath-crystalloidal biohermal facies (500-600 m)
 - Massive light grey limestone (600-700 m)
 - Stratolitic limestone (700-800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (800-900 m)
 - Archeocyath-crystalloidal biohermal facies (900-1000 m)
 - Massive light grey limestone (1000-1100 m)
 - Stratolitic limestone (1100-1200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (1200-1300 m)
 - Archeocyath-crystalloidal biohermal facies (1300-1400 m)
 - Massive light grey limestone (1400-1500 m)
 - Stratolitic limestone (1500-1600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (1600-1700 m)
 - Archeocyath-crystalloidal biohermal facies (1700-1800 m)
 - Massive light grey limestone (1800-1900 m)
 - Stratolitic limestone (1900-2000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (2000-2100 m)
 - Archeocyath-crystalloidal biohermal facies (2100-2200 m)
 - Massive light grey limestone (2200-2300 m)
 - Stratolitic limestone (2300-2400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (2400-2500 m)
 - Archeocyath-crystalloidal biohermal facies (2500-2600 m)
 - Massive light grey limestone (2600-2700 m)
 - Stratolitic limestone (2700-2800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (2800-2900 m)
 - Archeocyath-crystalloidal biohermal facies (2900-3000 m)
 - Massive light grey limestone (3000-3100 m)
 - Stratolitic limestone (3100-3200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (3200-3300 m)
 - Archeocyath-crystalloidal biohermal facies (3300-3400 m)
 - Massive light grey limestone (3400-3500 m)
 - Stratolitic limestone (3500-3600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (3600-3700 m)
 - Archeocyath-crystalloidal biohermal facies (3700-3800 m)
 - Massive light grey limestone (3800-3900 m)
 - Stratolitic limestone (3900-4000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (4000-4100 m)
 - Archeocyath-crystalloidal biohermal facies (4100-4200 m)
 - Massive light grey limestone (4200-4300 m)
 - Stratolitic limestone (4300-4400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (4400-4500 m)
 - Archeocyath-crystalloidal biohermal facies (4500-4600 m)
 - Massive light grey limestone (4600-4700 m)
 - Stratolitic limestone (4700-4800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (4800-4900 m)
 - Archeocyath-crystalloidal biohermal facies (4900-5000 m)
 - Massive light grey limestone (5000-5100 m)
 - Stratolitic limestone (5100-5200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (5200-5300 m)
 - Archeocyath-crystalloidal biohermal facies (5300-5400 m)
 - Massive light grey limestone (5400-5500 m)
 - Stratolitic limestone (5500-5600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (5600-5700 m)
 - Archeocyath-crystalloidal biohermal facies (5700-5800 m)
 - Massive light grey limestone (5800-5900 m)
 - Stratolitic limestone (5900-6000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (6000-6100 m)
 - Archeocyath-crystalloidal biohermal facies (6100-6200 m)
 - Massive light grey limestone (6200-6300 m)
 - Stratolitic limestone (6300-6400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (6400-6500 m)
 - Archeocyath-crystalloidal biohermal facies (6500-6600 m)
 - Massive light grey limestone (6600-6700 m)
 - Stratolitic limestone (6700-6800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (6800-6900 m)
 - Archeocyath-crystalloidal biohermal facies (6900-7000 m)
 - Massive light grey limestone (7000-7100 m)
 - Stratolitic limestone (7100-7200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (7200-7300 m)
 - Archeocyath-crystalloidal biohermal facies (7300-7400 m)
 - Massive light grey limestone (7400-7500 m)
 - Stratolitic limestone (7500-7600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (7600-7700 m)
 - Archeocyath-crystalloidal biohermal facies (7700-7800 m)
 - Massive light grey limestone (7800-7900 m)
 - Stratolitic limestone (7900-8000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (8000-8100 m)
 - Archeocyath-crystalloidal biohermal facies (8100-8200 m)
 - Massive light grey limestone (8200-8300 m)
 - Stratolitic limestone (8300-8400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (8400-8500 m)
 - Archeocyath-crystalloidal biohermal facies (8500-8600 m)
 - Massive light grey limestone (8600-8700 m)
 - Stratolitic limestone (8700-8800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (8800-8900 m)
 - Archeocyath-crystalloidal biohermal facies (8900-9000 m)
 - Massive light grey limestone (9000-9100 m)
 - Stratolitic limestone (9100-9200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (9200-9300 m)
 - Archeocyath-crystalloidal biohermal facies (9300-9400 m)
 - Massive light grey limestone (9400-9500 m)
 - Stratolitic limestone (9500-9600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (9600-9700 m)
 - Archeocyath-crystalloidal biohermal facies (9700-9800 m)
 - Massive light grey limestone (9800-9900 m)
 - Stratolitic limestone (9900-10000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (10000-10100 m)
 - Archeocyath-crystalloidal biohermal facies (10100-10200 m)
 - Massive light grey limestone (10200-10300 m)
 - Stratolitic limestone (10300-10400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (10400-10500 m)
 - Archeocyath-crystalloidal biohermal facies (10500-10600 m)
 - Massive light grey limestone (10600-10700 m)
 - Stratolitic limestone (10700-10800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (10800-10900 m)
 - Archeocyath-crystalloidal biohermal facies (10900-11000 m)
 - Massive light grey limestone (11000-11100 m)
 - Stratolitic limestone (11100-11200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (11200-11300 m)
 - Archeocyath-crystalloidal biohermal facies (11300-11400 m)
 - Massive light grey limestone (11400-11500 m)
 - Stratolitic limestone (11500-11600 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (11600-11700 m)
 - Archeocyath-crystalloidal biohermal facies (11700-11800 m)
 - Massive light grey limestone (11800-11900 m)
 - Stratolitic limestone (11900-12000 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (12000-12100 m)
 - Archeocyath-crystalloidal biohermal facies (12100-12200 m)
 - Massive light grey limestone (12200-12300 m)
 - Stratolitic limestone (12300-12400 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (12400-12500 m)
 - Archeocyath-crystalloidal biohermal facies (12500-12600 m)
 - Massive light grey limestone (12600-12700 m)
 - Stratolitic limestone (12700-12800 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (12800-12900 m)
 - Archeocyath-crystalloidal biohermal facies (12900-13000 m)
 - Massive light grey limestone (13000-13100 m)
 - Stratolitic limestone (13100-13200 m)
 - Bioclastic limestone with interbedded mudstone and crystalloidal and microbial laminations (13200-13300 m)
 - Archeocyath-crystalloidal biohermal facies (13300-13400 m)
 - Massive light grey limestone (13400-13500 m

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Table

		Sample #	True Thick-ness (m)	Comp		Hippon	?Brad	Hao	Mongo	
				<i>Jiucunella phaselo</i> sp. nov.	<i>Phasoia</i> cf. <i>spicata</i>	<i>Neokunminella moroensis</i> sp. nov.	<i>Sinskolutalla cuspidata</i> sp. nov.	<i>Jixinlingella daimonikoa</i> sp. nov.	<i>Mongolitubulus anhelios</i> sp. nov.	
WIRRAPOWIE FORMATION		1081.0 offset	~839.7	100+						
		1081	839.7	10 2						
		1070.5	831.4							
		1043	809.8	10	1	16	14			
		933.2	723.2	46						
		918.5	711.7	6 1						
WILKAWILLINA LIMESTONE	Winnitunny Creek Member	904.5	699.8	3						
		893	690.8	1	22 1					
		889	687.6	4	7 9					
		881.6	681	65+	1 9					
		Spot Loc Ab	1							
		Spot Loc C	6							
		866	668.7	31	1 2					
		855.3	660.3	3 1						
		848.5	654.9							
		844	651.4	9	4					
		Spot Loc D	73+	9	3					
		836.7	643	8	2					
		829.7	637.5	7						
		818.5	628.3	11	1					
		796.5	611.7	1						
		792.7	608.7	5	2					
		782.5	600.6							
		775	594.7	1						
		765	586.8							
		758.5	581.7							
		755.1	579							
		749	574.2							
		742.9	568.3	8						
		Spot Loc E	10							
	Hideaway Well Member	738	564.5	1						
		730	558.2							
		718	548.7							
		699.5	534.1	1						
		Total	242+	10	12	223+	19	23		