

1 A NEW LOWER CAMBRIAN SHELLY FOSSIL BIOSTRATIGRAPHY FOR SOUTH
2 AUSTRALIA

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16
17 ABSTRACT

18 Definition of early Cambrian chronostratigraphic boundaries is problematic with
19 many subdivisions still awaiting ratification. Integrated multi-proxy data from well-resolved
20 regional-scale schemes are ultimately the key to resolving broader issues of global correlation
21 within the Cambrian. In Australia, early Cambrian biostratigraphy has been based
22 predominantly on trilobites. Phosphatic shelly fauna have great potential as biostratigraphic

23 tools, especially in pre-trilobitic strata because they are widespread and readily preserved, but
24 they have remained underutilised. Here we demonstrate their value in a new biostratigraphic
25 scheme for the early Cambrian of South Australia using a diverse shelly fauna including
26 tommotiids, brachiopods, molluscs and bradoriids.

27 Biostratigraphic data are derived from ten measured stratigraphic sections across the
28 Arrowie Basin, targeting Hawker Group carbonates including the Wilkawillina, Wirrapowie
29 and Ajax limestones and the Mernmerna Formation. The stratigraphic ranges of shelly fossils
30 are predictable and repeatable across the Arrowie Basin, allowing three discrete shelly
31 biozones to be identified, spanning Terreneuvian, Stage 2 to Series 2, Stages 3–4. The
32 *Kulparina rostrata* Zone (new) and much of the overlying *Micrina etheridgei* Zone (new) are
33 pre-trilobitic (predominantly Terreneuvian). The Cambrian Series 2, Stage 3 *Dailyatia*
34 *odyssei* Zone (new) features a very diverse shelly fauna and will be described in detail in a
35 separate publication. These zones provide robust means to correlate early Cambrian
36 successions in neighbouring coeval basins in Australia, particularly the Stansbury Basin.
37 Wider correlation is possible throughout East Gondwana, especially with South China.

38 Key words:

39 Small shelly fossils; tommotiids; Cambrian; biostratigraphy; correlation.

40

41 1. INTRODUCTION

42 The Arrowie Basin is a large (55,000 km²) depositional basin situated in east-central
43 South Australia (Fig. 1) that has one of the best exposed successions of lower Cambrian
44 sedimentary packages anywhere in the world (Gravestock and Cowley, 1995; Zang et al.,
45 2004; Jago et al., 2012). Calcareous and organophosphatic shelly fossils (often called “Small

46 Shelly Fossils” [SSF]) are ubiquitous across carbonate-dominated parts of the basin and have
47 been described in a series of papers (Bengtson et al., 1990; Brock and Cooper, 1993; Brock
48 and Paterson, 2004; Paterson and Brock 2007; Skovsted et al., 2006, 2008, 2009a, 2009b,
49 2009c, 2011a, 2011b, 2012, 2015a, 2015b, 2016; Topper et al., 2007; 2009; 2011a; 2011b;
50 2013a; Betts et al., 2014; 2015, in press; Larsson et al., 2014; Jacquet et al., 2014; Jacquet
51 and Brock, 2015). This study integrates results derived from systematic sampling along 10
52 stratigraphic sections measured through the broadly coeval Wilkawillina, Wirrapowie and
53 Ajax limestones that crop out as distinctive folded tracts in the Flinders Ranges (Fig. 1): In
54 the north-west; the AJX-M and AJX-N (Figs. 2-3) sections. In the north-east; the MORO and
55 MOG sections (Figs. 4-5). In the central Flinders Ranges; WAR, BALC, MMT, the
56 Wilkawillina type section (WILK), and 10MS-W (Figs 6-10), and in the south; CR1 (Fig.
57 11). These stratigraphic sections intersect the lower part of the Hawker Group, from the
58 Parachilna Formation to the Second Plain Creek Member (upper Wilkawillina Limestone)
59 and Wirrapowie Limestones, and into the lower Mernmerna Formation (equivalent to
60 depositional sequence sets C1.1A, C1.1B, C1.2 of Gravestock and Cowley, 1995) (Fig.12).

61 The biozones defined herein are derived from a total of 694 stratigraphic horizons
62 sampled systematically at regular intervals (approximately 5–10 m) for shelly fossils. The
63 data from these 10 stratigraphic sections have been used to define new shelly fossil biozones,
64 reassess previously suggested schemes and discuss intrabasinal, regional and international
65 correlation of the lower Cambrian package in the Arrowie Basin, South Australia.

66 Some authors have raised doubts about the utility of early Cambrian fossils for
67 reliable biostratigraphic subdivision (Landing, 1994; Maloof et al., 2010; Landing and Geyer,
68 2012; Landing et al., 2013). The most often cited reasons for this include the strongly
69 endemic nature of many early Cambrian fauna and the diachronous appearances of key taxa
70 (Geyer, 2001; Peng et al., 2012). In response to this, chemostratigraphy has been suggested as

71 the method of choice for global correlation (Landing et al., 2013). However, there remains
72 some doubt regarding the application of chemostratigraphic data (Swart and Eberli 2005;
73 Swart 2008; Parkhaev, 2014). Biostratigraphic ranges of key early Cambrian shelly fossils
74 have been shown to be invaluable tools for relative dating and correlation (Devaere et al.,
75 2013; Guo et al., 2014; Rozanov, 1995; Steiner et al., 2004; Steiner et al., 2007; Yang et al.,
76 2014). Integration of regional biostratigraphic schemes, chemostratigraphic data are crucial to
77 solving broader issues of global correlation within the Cambrian system.

78

79 2. PREVIOUS BIOSTRATIGRAPHIC WORK

80 Early contributions to provide stratigraphic context to the succession of Cambrian
81 strata in the Flinders Ranges were made by Robert Etheridge (Etheridge, 1890), Griffith
82 Taylor (Taylor, 1910), Walter Howchin (Howchin, 1922, 1925), Robert Bedford (Bedford
83 and Bedford, 1939 and references therein), Douglas Mawson (Mawson, 1937, 1938, 1939)
84 and R.W. Segnit (Segnit, 1939). Daily (1956) produced the first biostratigraphy of the lower
85 Cambrian succession of South Australia by establishing 12 informal "faunal assemblages"
86 that were (until relatively recently) widely used for broad regional correlation in South
87 Australia (see also Daily, 1972). Unfortunately, Daily's (1956) faunal assemblages were not
88 accompanied by formal taxonomic descriptions or definition of precise boundaries. In
89 addition, only general locality data and vague stratigraphic ranges of the most important
90 diagnostic taxa were provided, preventing accurate correlation across and between adjacent
91 basins (Jago et al., 2006; Paterson and Brock, 2007). Cooper and Jago (2007) outlined the
92 history of investigations into South Australian Cambrian biostratigraphy.

93 Subsequent biostratigraphic schemes have been based on a variety of fossil groups
94 (see reviews by Zang, 2002; Jago et al., 2006, 2012; Paterson and Brock, 2007; Kruse et al.,

95 2009), with separate zonations based on archaeocyaths (Walter, 1967; Gravestock 1984;
96 Zhuravlev and Gravestock, 1994), trilobites (Jell in Bengtson et al., 1990) and acritarchs
97 (Zang et al., 2007). In the absence of a local stage subdivision specifically for the Australian
98 lower Cambrian, previous workers such as Gravestock and Cowley (1995), Brock and
99 Cooper (1993), Shergold (1996), Young and Laurie (1996), Brock et al., (2000), Gravestock
100 et al., (2001), Jago et al., (2006; 2012) and Kruse et al., (2009) have correlated the Australian
101 lower Cambrian successions (not always very successfully) with the widely used Siberian
102 stage subdivision (Nemakit-Daldynian, Tommotian, Atdabanian, Botoman and Toyonian) in
103 the sense of Rozanov and Sokolov (1984).

104

105 3. AIMS and METHODS

106 In an attempt to fill this knowledge lacuna, a comprehensive fieldwork campaign over
107 the last decade has resulted in systematic collection of fossiliferous, sedimentologic and
108 geochemical samples from more than 20 separate stratigraphic sections and over 100
109 supplementary spot localities that, in composite, intersect the entire lower Cambrian
110 succession in the Arrowie and Stansbury Basins. This comprehensive sampling has produced
111 in excess of 1000 separate, stratigraphically constrained microfossil data points. Standard
112 acetic acid leaching techniques were used to extract shelly material from the carbonates (see
113 methods in Skovsted et al., 2012, Guo et al., 2014), that have yielded a great diversity and
114 abundance of phosphatic, secondarily phosphatised and silicified shelly fossil groups.
115 Microfossils were picked from dried residues using a binocular stereo microscope, and
116 imaged with the JEOL JSM-6480LA and JEOL 7100FE Analytical Scanning Electron
117 Microscopes in the Microscopy Unit, Department of Biological Sciences at Macquarie
118 University.

119 The collected faunal data are presented in two parts – the biostratigraphic scheme
120 herein is derived from 10 stratigraphic sections intersecting a broad suite of carbonate facies
121 in the lower Hawker Group of the Arrowie Basin (Fig. 1). This part of the succession
122 includes the broadly coeval Wilkawillina, Wirrapowie and Ajax limestones occurring below
123 the regionally significant hiatus called the “Flinders Unconformity” (Gravestock and Cowley,
124 1995; Gravestock and Shergold, 2001) in the Arrowie Basin. Biostratigraphic analysis of the
125 overlying succession (Mermerna Formation and equivalents) is currently in preparation and
126 will be published separately.

127 This work provides detailed fossil range data facilitating construction of a new
128 biostratigraphic zonation of the lower Cambrian succession of South Australia (Terreneuvian,
129 Stage 2 to Series 2, Stages 3–4). As a first step in establishing this new regional
130 biostratigraphic framework, the aim of this paper is to formally name and define three new
131 shelly fossil biozones (in ascending order) – the *Kulparina rostrata* Zone, the *Micrina*
132 *etheridgei* Zone and the *Dailyatia odyssei* Zone. These zones can be correlated intra-basinally
133 across a broad suite of synchronous carbonate-dominated facies represented by the
134 Wilkawillina, Wirrapowie and Ajax limestones as well as inter-basinally with the broadly
135 synchronous fossiliferous packages in the Stansbury and Officer Basins in South Australia,
136 and the Amadeus Basin in the Northern Territory. They also have faunal ties with early
137 Cambrian strata in China, Avalonia, Laurentia and Siberia.

138 The biozones established here are based on the most abundant, widespread (at least
139 within the basin), readily identifiable and best preserved taxa, including tomotiids,
140 brachiopods, molluscs, and bradoriid arthropods. The *Kulparina rostrata* Zone and part of the
141 *Micrina etheridgei* Zone are pre-trilobitic, at least in terms of East Gondwanan trilobite
142 occurrences (see discussion below on the correlation of Australian lower Cambrian trilobite
143 zones with the global assemblages).

144 Though many SSF and associated taxa are now understood to have had a truly global
145 distribution, strong provincialism of many taxa (Larsson et al., 2014; Skovsted et al., 2015a,
146 2015b) and time lags between origination, dispersal and first appearance has hindered
147 application of SSF as tools for global biostratigraphic correlation (Landing et al., 2013).
148 Resolution of regional or basin-scale sequences is fundamentally important for global
149 chronostratigraphy, especially when using complementary methods such as isotope
150 chemostratigraphy. The International Commission on Stratigraphy (ICS) encourages the
151 integration of a variety of methods to independently correlate proposed chronostratigraphic
152 schemes (Remane et al., 1996). This is echoed by authors such as Geyer (2001), Landing et
153 al. (2013), Babcock et al. (2015), and Smith et al. (2014, 2015), who strongly advocate the
154 integration of independent chronostratigraphic data such as isotopic chemostratigraphy (and
155 magnetostratigraphy, where possible) with biostratigraphic schemes. Hence, samples for
156 chemostratigraphic analyses were collected alongside biostratigraphic samples with the aim
157 of integrating the biostratigraphy and lithostratigraphy with isotopic curves (for example, see
158 Zhu et al., 2006; Betts et al., 2015). This will facilitate high resolution intra-basin correlation
159 in addition to correlation between neighbouring basins (e.g. Stansbury Basin), and should
160 also contribute to efforts in global correlation of the lower Cambrian. Integration of
161 chemostratigraphic data with the biostratigraphic scheme presented here is currently in
162 progress and will be published separately.

163

164 4. HAWKER GROUP - STRATIGRAPHIC REVIEW

165 The Hawker Group (Dalgarno, 1964) represents approximately 4200 m of carbonate-
166 dominated formations cropping out in broad synclinal tracts in the central part of the Arrowie
167 Basin (Fig. 1). The Hawker Group succession is represented by sequence set $\epsilon 1.0$ of

168 Gravestock (1995) that now includes five disconformity-bounded sedimentary sequences
169 (Zang et al., 2004; Jago et al., 2012). The lowest Cambrian sequence, $\epsilon 1.0$, consists of
170 prodeltaic and deltaic siltstones and sandstones of the Uratanna Formation, which
171 disconformably underlie Hawker Group rocks, deposited in valleys cut into the Ediacaran
172 Rawnsley Quartzite. The Uratanna Formation has limited distribution in the Arrowie Basin
173 and where it is absent, the Parachilna Formation (lowermost unit of the Hawker Group)
174 disconformably overlies the Rawnsley Quartzite (Gravestock, 1995; Zang et al., 2004; Jago et
175 al., 2012). For detailed reviews of the stratigraphy and lithology of the Hawker Group
176 succession see Dalgarno (1964), Haslett (1975), Clarke (1986a, 1986b, 1986c, 1990a, 1990b),
177 Gravestock (1988), Gravestock and Cowley (1995), Zang et al. (2004), Paterson and Brock
178 (2007), and Jago et al. (2006; 2012).

179

180 4.1 Parachilna Formation and Woodendinna Dolostone (Sub-sequence $\epsilon 1.1A$)

181 Sub-sequence $\epsilon 1.1A$ contains the lowstand to transgressive Parachilna Formation and
182 conformably overlying highstand Woodendinna Dolostone. This sequence package is
183 terminated by a disconformable surface in the Bunkers Graben and overlain by the lower
184 Wilkawillina Limestone (Mt. Mantell Member) which incises into the Woodendinna
185 Dolostone at some localities (Zang et al., 2004). Six stratigraphic sections (AJX-M, AJX-N,
186 WAR, BALC, MMT, MORO; see Fig. 12) intersect or are measured from the Parachilna
187 Formation, an iron-rich, fine- to coarse-grained, cross-bedded, quartz-rich sandstone with
188 thinly bedded siltstone or shale. The upper part of the formation is heavily bioturbated with
189 abundant *Diplocraterion parallelum* Torell, 1870; such vertical “piperock” is used by
190 Mángano and Buatois (2014) to define Cambrian Stage 2 on a global scale.

191 The Woodendinna Dolostone is a highstand systems tract with microbialites, oncolites
192 and low stromatolite bioherms deposited in shallow marine carbonate shelf to supratidal
193 settings (Haslett 1975). The unit crops out in both the WILK and 10MS-W sections in the
194 Bunkers Graben (Figs 9 and 10, respectively) and the MORO section on the eastern limb of
195 the Arrowie Syncline (see Fig. 12). The unit is pervasively dolomitised and as a result is often
196 strongly weathered and poorly outcropping and shelly fossils have not been recovered.

197

198 4.2 Lower Wilkawillina Limestone (Sub-sequence ϵ 1.1B)

199 Sub-sequence ϵ 1.1B commences with the Mt. Mantell Member of the lower
200 Wilkawillina Limestone (Clarke, 1986a), representing a shallow shelf carbonate with
201 apparent lateral facies changes that passes basinwards (eastwards) into the Wirrapowie
202 Limestone that contains the oldest known archaeocyaths in Australia (Jago et al., 2012). The
203 disconformity between the Woodendinna Dolostone (ϵ 1.1A) and the lower Wilkawillina
204 Limestone (ϵ 1.1B) is only manifest on shallow carbonate shelf areas and there does not
205 appear to be a corresponding break within the Wirrapowie Limestone (for instance, in section
206 CR1; Fig. 11).

207 The Mt. Mantell Member was originally defined on shallow platform successions in
208 the Bunkers Graben and Range (Clarke, 1986a) and is intersected by stratigraphic sections
209 BALC (61.56 m), MMT (20.25 m), WILK (25.0 m), and 10MS-W (33.53 m) (Fig. 12). A
210 relatively thick, equivalent package of lower Wilkawillina Limestone occurs in the eastern
211 Arrowie Syncline in the MORO section (Fig. 4). The Mt. Mantell Member is a high energy,
212 shallow platform carbonate interpreted to have been deposited above wave base (Clarke,
213 1986a, 1990a; Betts et al., 2014). In all sections, deposition of the Mt. Mantell Member is
214 strongly microbially mediated (*Renalcis* and *Epiphyton*), with limestones fabrics often

215 exhibiting a clotted appearance and massive outcrop style. Although transported
216 archaeocyath fragments, laminate microbialites and stromatolites occur, no shelly fossils have
217 been recorded from the Mt. Mantell Member.

218 The Hideaway Well Member conformably overlies the Mt. Mantell Member and
219 crops out in the BALC (42.07 m), MMT (47.87 m), WILK (30.0 m), and 10MS-W (54.38 m)
220 sections in the central Flinders Ranges, and at the MORO (59.0 m) section in the Arrowie
221 Syncline in the north-east Flinders Ranges (Fig. 12). The Hideaway Well Member is
222 characterised by increased abundance of archaeocyaths, both fragmentary and *in situ*, and
223 relatively large bioherms are commonly developed in this member, with some measuring up
224 to 100 m in lateral extent in the MORO section (Betts et al., 2014). The Hideaway Well
225 Member represents a high-energy, shallow water carbonate environment and also preserves
226 the oldest shelly fauna known from the Arrowie Basin.

227 The Winnitiny Creek Member (Clarke 1986a) of the Wilkawillina Limestone
228 conformably overlies the Hideaway Well Member and is intersected in the BALC (94.74 m),
229 MMT (169.29 m), WILK (145.0 m), and 10MS-W (108.76 m) sections in the Bunkers
230 Graben and Range, and the MORO (135.0 m) and MOG (62.65 m) sections in the Arrowie
231 Syncline (Figs 1, 12). Archaeocyaths occur throughout the Winnitiny Creek Member,
232 though it is chiefly characterised by a very abundant and diverse shelly fauna. This
233 assemblage includes a wide variety of brachiopods, tomotiids, helcionellid and bivalved
234 molluscs, bradoriid arthropods, sponge spicules and rare echinoderm plates. Trilobites are
235 also known to occur in the upper parts of the member with *Elicicola calva* Jell in Bengtson et
236 al., 1990 described by Paterson and Brock (2007, p. 138-139, fig. 13) from the base of the
237 MMF section in the Bunkers Range. The palaeoenvironment is interpreted to have been of
238 lower energy compared to the preceding Hideaway Well Member, though deposition was still
239 on the carbonate shelf (Betts et al., 2014). The Winnitiny Creek Member interfingers with

240 coeval ribbon carbonates of the Wirrapowie Limestone in the MORO and MOG sections
241 north of the Wirrealpa Hinge Zone (Fig. 1).

242 In sections on the shallow carbonate shelf in the central Flinders Ranges (Wirrealpa
243 Hinge Zone of Gravestock and Cowley, 1995), the Winnitiny Creek Member is truncated by
244 a distinctive red, karstic surface. This represents a regionally significant hiatus called the
245 “Flinders Unconformity” (FU) (James and Gravestock, 1990) that defines the top of sequence
246 package $\epsilon 1.1B$ in shallow shelf facies (Gravestock and Shergold 2001; Zang et al., 2004;
247 Jago et al., 2012) and separates the lower and upper Wilkawillina Limestones in the Bunkers
248 Graben (Clarke, 1986b). The FU represents a period of diachronous sub-aerial exposure and
249 erosion of the Wilkawillina Limestone in shallow shelf settings succeeded by deposition of
250 iron-rich micro-stromatolitic microbialites during a transgression event. The disconformable
251 surface does not occur (or is not apparent) in all sections, particularly those to the south
252 (10MS-W) and the north (MORO and MOG) (Fig. 12) of the Wirrealpa Hinge Zone,
253 indicating that pronounced breaks in sedimentation did not occur in all localities across the
254 Arrowie Basin (see also James and Gravestock 1990, p. 458-459).

255

256 4.3 Wirrapowie Limestone (Sequence $\epsilon 1.1$)

257 The Wirrapowie and Wilkawillina Limestones are coeval carbonate facies
258 representing adjacent, interfingering platform and restricted lagoonal palaeoenvironments,
259 respectively (Haslett, 1975) (Fig.12). Lack of cross-bedding, quartz grains and other coarse
260 detrital material indicate a predominantly low energy regime, and lack of mud-cracks, halite
261 casts and other evidence of subaerial exposure indicates that the environment remained
262 consistently submerged (Haslett, 1975). There is no evidence of the disconformity separating
263 sub-sequence sets $\epsilon 1.1A$ and B in the Wirrapowie Limestone. Higher energy facies are

264 represented by occasional oolitic beds and sporadic, high energy events resulting in the
265 deposition of intraformational conglomerates and breccias (as in the WAR section; Fig. 6).
266 Coeval deposition of the Wirrapowie and Wilkawillina limestones is confirmed by the
267 synchronous ranges of brachiopods, tommotiids and bradoriids in both facies.

268

269 4.4 Ajax Limestone (Sub-Sequence ϵ 1.1B and Sequence ϵ 1.2)

270 The Ajax Limestone (Fig. 1–3) crops out in the Mt. Scott Range in the northeast of
271 the Arrowie Basin. The lower 110–120 m was deposited as part of systems tract ϵ 1.1B,
272 broadly equivalent to the lower Wilkawillina and Wirrapowie limestones. The reddened
273 horizon of the Flinders Unconformity is not apparent in AJX-M or AJX-N sections, and there
274 is a transition to sequence package ϵ 1.2 which is truncated by a disconformity surface near
275 the top of the AJX-M section (Fig. 2). Shallow water facies including stromatolitic
276 boundstones dominate the lower 120 m of the AJX-M section. This is overlain by shelly
277 fossil and archaeocyath rich nodular limestones and bioclastic limestones (Fig. 2; see also
278 Brock et al., 2006; Skovsted et al., 2009a).

279

280 4.5 Second Plain Creek Member (Wilkawillina Limestone) and lower Mernmerna Formation 281 (Sequence ϵ 1.2)

282 The Second Plain Creek Member of the Wilkawillina Limestone (“middle
283 Wilkawillina Limestone” of Gravestock and Hibburt (1991) only outcrops in the Bunkers
284 Graben (WILK, Figs. 9, 12). The Second Plain Creek Member is interpreted to have been
285 deposited on a starved carbonate platform during rapid transgression and is transitional

286 between the relatively shallow facies of the Winnitunny Creek Member and the deeper outer
287 shelf facies of the overlying Mernmerna Formation (Clarke, 1986b).

288 The Mernmerna Formation is subdivided into three members, from lowest to highest;
289 the Six Mile Bore Member, the Linns Springs Member and the Third Plain Creek Member
290 (Clarke, 1986c). The Mernmerna Formation crops out in the MMT (7.5 m) and MOG (369.8
291 m) sections and Bunkers Graben where WILK and 10MS-W were measured (the WILK and
292 10MS-W sections terminate at the boundary between the Wilkawillina Limestone and the
293 Mernmerna Formation) (Fig. 12). The duration of the hiatus represented by the disconformity
294 between the top of the Winnitunny Creek Member of the lower Wilkawillina limestone
295 (Sequence $\epsilon 1.1B$) and the outer shelf deposits of Mernmerna Formation (Sequence $\epsilon 1.2$) is
296 variable. Most sections on the shallow platform are missing all or large parts of the lower
297 Mernmerna Formation due to lack of deposition (e.g. BALC, Fig. 7 and MMT, Fig. 8
298 sections).

299 The nodular limestones of the Mernmerna Formation (Sequence $\epsilon 1.2$) are interpreted
300 to have been deposited in low energy, outer shelf, ramp and slope settings (Haslett, 1975;
301 Daily, 1976), with input of allochthonous carbonates containing slumps or slide structures
302 (Clarke, 1990c; Gravestock, 1995) representing active shelf collapse and slope processes.

303

304 5. NEW BIOSTRATIGRAPHIC ZONES

305 Distinctive shelly fossil assemblages recur consistently throughout all measured
306 sections within carbonate packages of subsequence $\epsilon 1.1B$ in the lower Hawker Group, and
307 permit the establishment of three successive biozones. The *Kulparina rostrata* Zone has
308 relatively low diversity shelly fauna, but is characterised by overlapping or partially

309 overlapping ranges of tommotiids and a paterinid brachiopod. The overlying *Micrina*
310 *etheridgei* Zone is represented by a high diversity assemblage containing a mix of
311 tommotiids, brachiopods, molluscs and arthropods. The base of the *Dailyatia odysesei* Zone is
312 broadly equivalent with the base of sequence package $\epsilon 1.2$, and is formally defined, but full
313 description of the taxa associated with this zone and its regional and global correlation is
314 currently in preparation and will be published separately.

315

316 5.1 *Kulparina rostrata* Zone

317 The *K. rostrata* Zone occurs in the Hideaway Well Member and lower half of the
318 Winnitunny Creek Member of the Wilkawillina Limestone (e.g. MORO, Fig. 4; BALC, Fig.
319 7; MMT, Fig. 8; WILK, Fig. 9) and the lower 430 m of the Wirrapowie Limestone in the
320 WAR (Fig. 6) and CR1 sections (Figs. 11-12). The designated reference section is 10MS-W
321 (Fig. 10, Appendix 9). Diversity within the zone is relatively low, typically containing five or
322 six taxa including eccentrothecimorph and camenellan tommotiids and a paterinid
323 brachiopod.

324

325 5.1.1 Lower Boundary

326 The lower boundary of the *K. rostrata* Zone is defined by the first occurrence of either
327 the eccentrothecimorph tommotiid *Kulparina rostrata* Conway Morris and Bengtson *in*
328 Bengtson, Morris, Cooper, Jell and Runnegar, 1990 (Fig. 13H-N, Q) or the paterinid
329 brachiopod *Askepasma saproconcha* Topper, Holmer, Skovsted, Brock, Balthasar, Larsson,
330 Petterson Stolk and Harper, 2013 (Fig. 13A-G).

331

332 5.1.2 Upper Boundary

333 The upper boundary of the *K. rostrata* Zone is coincident with the base of the
334 overlying *M. etheridgei* Zone based on the first occurrence of either *M. etheridgei* or *A.*
335 *toddense*. In 10MS-W (Fig. 10) and CR1 (Fig. 11) the last occurrence of *K. rostrata* and the
336 first occurrences of either *M. etheridgei* or *A. toddense* are in the same horizon. In all other
337 sections, ranges of both *K. rostrata* and *A. saproconcha* are completely restricted to within
338 the zone. The upper boundary of the *K. rostrata* Zone in all sections is located below the
339 incoming of trilobites in East Gondwana.

340

341 5.1.3 Accessory Taxa

342 Accessory taxa in the *K. rostrata* Zone include the camenellan tommotiids *Dailyatia*
343 *ajax* Bischoff, 1976 (Fig. 14A-G), *Dailyatia macroptera* (Tate, 1892) (Fig. 14H-K),
344 *Dailyatia bacata* Skovsted, Betts, Topper and Brock, 2015 (Fig. 14P-S) and *Dailyatia helica*
345 Skovsted, Betts, Topper and Brock, 2015 (Fig. 14L-O) (see also Skovsted et al. 2015).
346 *Dailyatia ajax* and *D. macroptera* have stratigraphic ranges that extend below (e.g. BALC,
347 Fig. 7; CR1; Fig. 11) and above the defined boundaries of the *K. rostrata* Zone. *Dailyatia*
348 *bacata* and *D. helica* have first occurrences in the *K. rostrata* Zone but range into the
349 overlying *M. etheridgei* Zone. The eccentrothecimorph tommotiid *Paterimitra pyramidalis*
350 Laurie, 1986 also has a first occurrence in this zone and ranges into the overlying *M.*
351 *etheridgei* and *D. odyssei* zones (Fig. 13, O-P, R-V).

352 Shields attributed to *Sinskolutella cuspidata* Betts, Topper, Valentine, Skovsted,
353 Paterson, and Brock, 2014 based on distinctive dactyloscopic microornament (Fig. 19, E-H,
354 see Betts et al. 2014, fig. 6) occur in the *K. rostrata* Zone in the MMT section; the lowest

355 known occurrence of bradoriids in the Arrowie Basin (Fig. 8, Appendix 7). However,
356 occurrence *S. cuspidata* in the *M. etheridgei* Zone (MORO and MOG sections), and
357 potentially also the *D. odyssei* Zone (unpublished data), suggests a long stratigraphic range
358 for this taxon, spanning pre-trilobitic to *P. janeae* Zone strata.

359

360 5.2 *Micrina etheridgei* Zone

361 The *Micrina etheridgei* Zone is restricted to the upper half of the Winnitiny Creek
362 Member of the Wilkawillina Limestone and temporal equivalents in the Wirrapowie and Ajax
363 limestones. Diversity within the zone is relatively high (~28 species in the AJX-M section),
364 including eccentrothecimorph and camenellan tommotiids, organophosphatic brachiopods,
365 helcionelloid molluscs, bradoriid arthropods and lobopods.

366

367 5.2.1 Lower Boundary

368 The *Micrina etheridgei* Zone is often highly fossiliferous (e.g. MMT section,
369 Appendix 7). The lower boundary is defined by the first occurrence of the tannuolinid
370 tommotiid *Micrina etheridgei* (Tate, 1892) (Fig. 15J-P) or the paterinid brachiopod
371 *Askepasma toddense* (Fig. 16A-H). *Askepasma toddense* Laurie, 1986 (Fig. 16A-H) has a
372 mutually exclusive stratigraphic range with the older (possibly ancestral) *Askepasma*
373 *saproconcha*. *Askepasma toddense* ranges from the Winnitiny Creek Member of the
374 Wilkawillina Limestone into the Second Plain Creek Member (WILK, Fig. 9) above the FU.
375 A taxon similar to *A. toddense* occurs in the *D. odyssei* Zone in the Mernmerna Formation,
376 though these are typically poorly preserved and may be reworked (MOG section, Fig. 5; Fig.
377 16C).

378

379 5.2.2 Upper Boundary

380 The upper boundary of the *M. etheridgei* Zone is coincident with the base of the
381 overlying *D. odyssei* Zone based on the first occurrence of *Dailyatia odyssei* Evans and
382 Rowell, 1990 or *Stoibostrombus crenulatus* Conway Morris and Bengtson in Bengtson et al.,
383 1990. In sections measured through platformal carbonates in the central Flinders Ranges (Fig.
384 1) such as BALC (Fig. 7), MMT (Fig. 8), WILK (Fig. 9), 10MS-W (Fig. 10) the *M.*
385 *etheridgei* Zone is capped by the regionally significant Flinders Unconformity (FU). This
386 surface is manifest as a distinctive karstic microstromatolitic “reddened horizon” (Gravestock
387 and Cowley 1995). The duration of this hiatus is variable across the Arrowie Basin (see also
388 James and Gravestock 1990, p. 458-459). The duration of the unconformity in the WILK
389 section for example, represents an unknown period of subaerial exposure and non-deposition
390 (Fig. 9). Here, the upper boundary of the *M. etheridgei* is delineated by the karstic surface.
391 *Micrina etheridgei* (as well as accessory taxa *Dailyatia ajax*, *D. macroptera*, *D. helica* and *D.*
392 *bacata*) does not occur stratigraphically above the “reddened horizon”.

393

394 5.2.3 Accessory Taxa

395 Shelly taxa that have first occurrences within the *M. etheridgei* Zone include a
396 number of organophosphatic brachiopods, helcionelloid molluscs, bradoriids and lobopods,
397 some of which have correlative potential (see below). Accessory taxa include *D. ajax*, *D.*
398 *macroptera*, *D. helica* and *D. bacata* which range from the underlying *K. rostrata* Zone and
399 terminate within the *M. etheridgei* zone.

400 Organophosphatic brachiopods such as *Eoobolus* spp. (which includes
401 *Sukaharilingula* Ushatinskaya 2012), *Karathele yorkensis* Holmer and Ushatinskaya in
402 Gravestock et al., 2001 (Popov et al., 2015, p. 32, have recently synonymized *Karathele* with
403 *Schizopholis*), *Eodicellomus elkaniiformis* Holmer and Ushatinskaya in Gravestock et al.,
404 2001, and *Kyrshabaktella davidi* Holmer and Ushatinskaya in Gravestock et al., 2001 (Fig.
405 16 I-U and Fig. 17 A-T) all have first occurrences in the *M. etheridgei* Zone, but range into
406 the overlying *D. odyssei* Zone.

407 The tommotiid *Eccentrotheca helenia* Skovsted, Brock, Topper, Paterson and
408 Holmer, 2011 (Fig. 15, A-D) first occurs in the *M. etheridgei* Zone. First appearance of *E.*
409 *helenia* has been taken as a proxy for the lower boundary of the *A. huoi* Zone. This level
410 consistently occurs above the defined lower boundary of the *M. etheridgei* Zone (Fig. 4; see
411 also Betts et al., 2014, fig. 2), demonstrating that the lower part of the zone is pre-trilobitic.

412 The *M. etheridgei* Zone records the first occurrences of a number of helcionelloid
413 molluscan taxa that range into the overlying *D. odyssei* Zone (Fig. 18). Taxa include
414 *Pelagiella subangulata* (Tate, 1892), *Anabarella australis* Runnegar in Bengtson et al., 1990
415 and *Mackinnonia rostrata* (Zhou and Xiao, 1984), often preserved as steinkerns (Fig. 18).
416 The difficulty in accurately identifying steinkern material to species level makes utilisation of
417 these taxa problematic in biostratigraphic schemes (see also discussion by Jacquet and Brock
418 2015). *Pelagiella subangulata* has been suggested as a possible proxy to define the base of
419 Series 2, Stage 3 on a global scale (see Peng et al., 2012). Whilst some steinkerns probably
420 represent *P. subangulata* (Fig. 18A, D; AJX-M, Fig. 2, AJX-N, Fig. 3, MORO, Fig. 4, MOG,
421 Fig. 5), we take a cautious taxonomic approach and acknowledge the difficulties of
422 confidently identifying steinkern material to species level.

423 The *M. etheridgei* Zone hosts a unique assemblage of bradoriids that are restricted to
424 the zone (~10 species) (Figs. 19, 20), key amongst these are *Liangshanella circumbolina*
425 Topper, Skovsted, Brock & Paterson, 2011, *Quadricona madonnae* Topper, Skovsted, Brock
426 & Paterson, 2011 (Fig. 20, E, F) and *Zepaera jagoi* Topper, Skovsted, Brock & Paterson,
427 2011 (Topper et al., 2011). The range of the Chinese taxon *Parahoulongdongella*
428 *bashanensis* (Shu, 1990) is also restricted to the *M. etheridgei* Zone (Fig. 20, A-D). Endemic
429 taxa include *Jiucunella phaseloia* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014
430 (Fig. 19, A-D) is restricted to the *M. etheridgei* Zone. Similarly, the haoiid *Jixinlingella*
431 *daimonikoa* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19. S-U),
432 *Mongolitubulus anthelios* Betts, Topper, Valentine, Skovsted, Paterson, Brock, 2014 (Fig. 19,
433 M-R) and *Neokunmingella moroensis* Betts, Topper, Valentine, Skovsted, Paterson, Brock,
434 2014 (Fig. 19. I-L) occur only in the *M. etheridgei* Zone (MORO and MOG, Figs. 4-5). A
435 distinctive new species of *Mongolitubulus* (Fig. 20 J-K) occurs in the *M. etheridgei* Zone in
436 CR1/589.7 (Appendix 10) and MOG 114.1 (63.7 m true thickness from base).
437 *Mongolitubulus* spines are abundant throughout these sections though abraded specimens are
438 difficult to assign to species.

439 Other shelly fossils in the *M. etheridgei* Zone include sclerites of the lobopodian
440 *Microdictyon* Bengtson, Matthews and Missarzhevsky in Missarzhevsky and Mambetov,
441 1981 (Fig. 21, T-V). The FAD of *M. effusum* may be utilised to define the base of Cambrian
442 Series 2, Stage 3 where trilobites might be absent (Peng et al., 2012). Steiner et al., (2007)
443 noted *Microdictyon effusum* Bengtson, Matthews and Missarzhevsky in Missarzhevsky and
444 Mambetov, 1981 as an accessory taxon in a number of biozones subdividing lower Cambrian
445 strata on the Yangtze Platform in South China. However, Topper et al., (2011a) suggested
446 that the morphology of *Microdictyon* sclerites can vary intraspecifically and also along the
447 trunk of a single animal. In the studied sections, *Microdictyon* sclerites have only been

448 recovered from AJX-M (Fig. 2), MORO (Fig. 4) and MOG (Fig. 5) and show a sporadic
449 stratigraphic distribution throughout the *M. etheridgei* Zone and into the overlying *D. odyssei*
450 Zone. This, coupled with taxonomic difficulties outlined by Topper et al., (2011a), precludes
451 the biostratigraphic application of *Microdictyon* at the specific level in the Arrowie Basin and
452 potentially elsewhere.

453

454 5.3 *Dailyatia odyssei* Zone

455 5.3.1. Lower Boundary

456 The lower boundary of the *Dailyatia odyssei* Zone is defined by the first appearance
457 of the camenellan tommotiid *Dailyatia odyssei* (Fig. 21. M-O), or the problematic
458 ecdysozoan *Stoibostrombus crenulatus* (Fig. 21. H-L). *Dailyatia odyssei* has a stratigraphic
459 range that is younger and, importantly, does not overlap the range of any other *Dailyatia*
460 species in South Australia (AJX-M, Figs 2, MOG, Fig. 5, WILK, Fig. 9). In the AJX-M
461 section, *D. odyssei* occurs in the uppermost 3.4 m of the *A. huoi* trilobite Zone (Fig. 2;
462 Appendix 1). However, *D. odyssei* has a long stratigraphic range encompassing the *Pararaia*
463 *tatei*, *P. bunyeroensis* and lowermost part of the *P. janeae* trilobite zones (Skovsted et al.,
464 2015a).

465 In MMT (Fig. 8), the Flinders Unconformity represents an unknown period of
466 subaerial exposure and non-deposition. The presence of the *D. odyssei* Zone is indicated by
467 the occurrence of *Stoibostrombus crenulatus* but does not represent the true base of the zone
468 due to the FU. In MMT, the Third Plain Creek Member of the Mernmerna Formation (*P.*
469 *bunyeroensis* trilobite Zone) rests directly on the Winnitiny Creek Member of the
470 Wilkawillina Limestone. Hence, the Six Mile Bore and Linns Springs members of the

471 Mernmerna Formation are missing in the MMT (Fig. 8) section and the true lower boundary
472 of the *D. odyssei* Zone cannot be accurately ascertained.

473 The FU also obscures the relationship between the *M. etheridgei* and *D. odyssei* zones
474 in WILK (Fig. 9). Here, the incoming of both *D. odyssei* and *S. crenulatus* is in the same
475 horizon in the Second Plain Creek Member (RS337/A), the first sample taken
476 stratigraphically above the FU. However, increased sampling between the samples directly
477 above and below the disconformity surface, would more clearly define the boundaries.
478 Additionally, in the BALC section (Fig. 7) the entire Mernmerna Formation (and therefore
479 the *D. odyssei* Zone) is completely absent due to lengthy hiatus at the FU (Fig. 22).

480

481 5.3.2. Accessory Taxa

482 Common taxa in the lower part of the *D. odyssei* Zone include tomotiids,
483 stoibostrombids, brachiopods and bradoriids (Figs. 19-21). The tomotiid *Lapworthella*
484 *fasciculata* Conway Morris and Bengtson in Bengtson et al., 1990 (Fig. 21A-G, K) has a first
485 occurrence in the underlying *M. etheridgei* Zone, but ranges up into the *D. odyssei* Zone
486 where it can be very abundant (e.g. WILK section, Appendix 8). *Paterimitra pyramidalis* also
487 ranges into the *D. odyssei* Zone from the *K. rostrata* Zone. Other problematic microfossils
488 associated with the *D. odyssei* Zone include *Protohertzina* sp. and *Mongolodus* sp. spines
489 (Fig. 21W, X).

490 Brachiopods in the *D. odyssei* Zone include *Eoobolus* spp., *Karathele yorkensis*,
491 *Kyrshabaktella davidii*, *Eodicellomus elkaniiformis*, *Minlatonia tuckeri* Holmer and
492 Ushatinskaya in Gravestock et al., 2001 (Figs 16I-U and 17A-T) which range up from the *M.*
493 *etheridgei* Zone. Other shelly taxa in the *D. odyssei* Zone include *Mickwitzia* sp. an

494 undescribed new genus of organophosphatic brachiopod (Fig. 21P-R). Helcionelloid molluscs
495 such as *Mackinnonia* Runnegar in Bengtson et al., 1990 (Fig 18N-U), *Anabarella* Vostokova,
496 1962 (Fig. 18I-M) and *Pelagiella* Matthew, 1895 (Fig. 18A-H) and bradoriids are also
497 abundant in the *D. odyssei* Zone, with many ranging up from the underlying *M. etheridgei*
498 Zone.

499

500 6. CORRELATION IN EAST GONDWANA

501 The new shelly fossil biozones defined here can be correlated across the Arrowie
502 Basin and with neighbouring depocentres such as the Stansbury, Officer, Amadeus and
503 Georgina basins.

504

505 6.1 Arrowie Basin

506 The oldest faunal assemblage (FA1) reported by Daily (1956) was based on shelly
507 material from the Flinders Ranges (Mt. Scott Range, Lake Frome and Wilson-Quorn areas).
508 This archaeocyath-rich assemblage also contains a single unidentified organophosphatic
509 (“atrematous”) brachiopod (Daily 1956, p. 129). Daily’s FA1 appears to largely overlap with
510 the *K. rostrata* Zone based on a rich archaeocyath fauna and low diversity shelly fauna (see
511 Fig. 22).

512 Daily (1956) noted that *Micromitra* (*Paterina*) *etheridgei* (= *Micrina etheridgei*
513 Laurie, 1986) was abundant in his faunal assemblage 2 (FA2). In the new biostratigraphic
514 scheme, we recognise the importance of *M. etheridgei* as a key faunal indicator and use it to
515 define the *M. etheridgei* Zone. In addition, Daily (1956) also noted the presence of

516 *Ambonychia macroptera* in FA2, now identified as the tommotiid species *Dailyatia*
517 *macroptera* (see Skovsted et al., 2015a), which first appears in the *K. rostrata* Zone and
518 ranges into the overlying *M. etheridgei* Zone. The brachiopod *Kutorgina peculiaris* (Tate,
519 1892) was also noted by Daily (1956) in FA2. *Askepasma saproconcha* may have been
520 misidentified as *K. peculiaris* by Daily (1956), which also has a relatively large sulcate shell
521 (see Walcott, 1912, pl. V, fig. 2), suggesting Daily's FA2 may partially overlap the *K.*
522 *rostrata* Zone and the *M. etheridgei* Zone.

523 Daily's (1956) FA3 and FA4 are trilobite-rich, and include helcionellids and hyoliths.
524 Jell in Bengtson et al., (1990, p.15) correlated Daily's FA3 with the *A. huoi* Zone based on
525 the occurrence of *Yorkella australis* Woodward, 1884 and *Abadiella huoi* Chang, 1966 (see
526 also Paterson and Brock, 2007). Daily's FA4 correlates with the *P. tatei* Zone based on the
527 occurrence of the eponym (Daily 1956, p. 130; Jell in Bengtson et al., 1990, p.15). Daily's
528 (1956) FA3 and FA4 are therefore likely to correlate with the upper *M. etheridgei* Zone and
529 the *D. odyssei* Zone, respectively. Correlation of Daily's (1956) faunal assemblages 1–4 with
530 the new biozones is shown in Figures 22 and 23.

531 Trilobites are currently the most readily utilised biostratigraphic tool for defining a
532 lower Cambrian biozonation in Australia. Jell in Bengtson et al., (1990) initially erected four
533 trilobite biozones – (from oldest to youngest): *Abadiella huoi*, *Pararaia tatei*, *P.*
534 *bunyerooensis*, and *P. janeae*. Paterson and Brock (2007) described a new faunal assemblage
535 within the *P. bunyerooensis* Zone in the Bunkers Range and recognised a close faunal
536 connection between the trilobites of South Australia and South China for this time interval.
537 They also noted that the first appearance of trilobites in the Arrowie Basin, including the
538 eponym of the oldest trilobite zone, *Abadiella huoi*, occurs in the upper half of the
539 Winnitny Creek Member of the Wilkawillina Limestone and equivalent strata in the Ajax

540 Limestone. The first appearance of *A. huoi* always occurs above the base of the *M. etheridgei*
541 Zone as defined here, though the zones overlap. The upper boundary of the *A. huoi* Zone, best
542 expressed in the AJX-M section, occurs 12 m stratigraphically above the top of the *M.*
543 *etheridgei* Zone where it overlaps with the lower boundary of the *D. odyssei* Zone (Fig. 2).

544

545 6.2 Stansbury Basin

546 The early Cambrian shelly fauna of the Stansbury Basin have been relatively well
547 studied. However, much of the taxonomic syntheses that underpin these early biostratigraphic
548 investigations (Bengtson et al., 1990; Gravestock et al., 2001) predate extensive modern
549 systematic treatments of key shelly fossil taxa from South Australia (see references herein).
550 The result is that it can be difficult to tease out the true biostratigraphic signals from these
551 monographs. Ultimately, only recollection of fossil material along measured stratigraphic
552 sections will resolve uncertainties in correlation with the Arrowie Basin.

553

554 6.2.1 Small Shelly Fossils

555 Gravestock et al., (2001) established three shelly fossil zones (from oldest to
556 youngest): *Hippopharangites dailyi*, *Halkieria parva* and *Kaimenella reticulata*. However,
557 the *Hippopharangites dailyi* and *Halkieria parva* biozones are based on taxa with poorly
558 understood multi-element scleritomes. Meagre illustrations of these species do not show all
559 sclerite types for each taxon, hindering meaningful taxonomic comparisons and their
560 biostratigraphic utility. Additionally, inconsistencies in the definitions of these zones have
561 prevented their widespread application.

562 *Kulparina rostrata* as originally described by Bengtson et al., (1990) is entirely
563 restricted to the upper part of the Kulpara Limestone at Horse Gully (= type locality).
564 Skovsted et al., (2011b, p. 281; see also Skovsted et al., 2015b) noted that the specimens
565 originally described as *Eccentrotheca guano* Bengtson in Bengtson et al., (1990, p. 119-120,
566 fig 71-73) from the Kulpara Limestone are actually sclerite morphotypes of *K. rostrata*. All
567 figured specimens of *K. rostrata* (Bengtson et al., 1990, Figs 71-73, 86-90) are derived from
568 two samples (6429RS103 and UNEL1858) located 8.0 m and 7.5 m, respectively, below the
569 disconformity between the Kulpara and Parara limestones. Re-examination of sample
570 6429RS104, 3.0 m below the disconformity in the upper Kulpara Limestone at Horse Gully
571 contains abundant *K. rostrata* along with *Dailyatia ajax*, *D. macroptera*, *D. bacata* and many
572 fragments of a paterinid brachiopod, attributable to *Askepasma saproconcha*. The occurrence
573 of *K. rostrata* cannot be confirmed above sample 6429RS104 (see Bengtson et al., 1990, fig.
574 4). Hence, the *K. rostrata* Zone occurs in a ~5.0 m interval between samples 6429RS103 and
575 6429RS104 in the Kulpara Limestone. The low diversity fauna in this interval also accords
576 with typical assemblages of the *K. rostrata* Zone in the Arrowie Basin.

577 Gravestock et al., (2001, fig.11) also reported the presence of *Kulparina cf. rostrata*
578 in the lower Parara Limestone in the SYC-101 drillcore, located 25 km south of Horse Gully.
579 None of this material was figured, however the fact that the taxon co-occurs with a
580 moderately high diversity shelly assemblage in the lower Parara Limestone, strongly suggests
581 that the specimens are not *K. rostrata*. Thus, there is no definitive evidence that *K. rostrata*
582 has a range that extends above the Kulpara Limestone on Yorke Peninsula.

583 Sample 6429RS105, located 1.0 m below the disconformity horizon at Horse Gully
584 (see Bengtson et al., 1990, fig. 4), contains a high diversity shelly assemblage (15+ taxa)
585 including *Micrina etheridgei*, *Dailyatia ajax*, *D. macroptera*, numerous hyoliths, spicules,
586 hyolithelminth tubes, *Sinosachites delicatus* (Jell, 1981), *Hippopharangites dailyi* Bengtson

587 in Bengtson et al., 1990 and *Eremactis* spp. Indeterminate paterinid fragments are also
588 present. This suggests the *M. etheridgei* Zone is restricted to a ~1.0 m interval directly
589 beneath the disconformity surface. Importantly, whilst *M. etheridgei* is reported in samples
590 immediately above the disconformity at Horse Gully by both Bengtson et al., (1990; sample
591 6429RS106) and Gravestock et al., (2001; samples HG0 and HG1) there is no record of *D.*
592 *ajax*, *D. macroptera*, *D. bacata* or *D. helica* above the disconformity. This suggests that the
593 disconformity surface in the western Stansbury Basin (at least at Horse Gully) may record a
594 significantly longer hiatus than the Flinders Unconformity on platform successions in the
595 Arrowie Basin. Both the *K. rostrata* Zone and the *M. etheridgei* Zone are represented by a
596 very narrow (possibly condensed) interval at Horse Gully.

597 The Parara Limestone succession overlying the disconformity surface at the Horse
598 Gully section contains a very diverse shelly fauna including halkieriids, hyoliths,
599 *Microdictyon*, bradoriids and the micromolluscs *Mackinnonia*, *Pelagiella* and *Anabarella*.
600 This level also contains *Stoibostrombus crenulatus* (in sample 6429RS106) and the trilobite
601 *Yorkella australis* (Jell in Bengtson et al., 1990), confirming that the lower part of the Parara
602 Limestone at Horse Gully correlates with the *D. odyssei* Zone in the Arrowie Basin (Fig. 22).

603 *Stoibostrombus crenulatus* is also reported in the Parara Limestone in SYC-101, CD-
604 2, and Port Julia-1A sections where it occurs with typical *D. odyssei* Zone taxa, such as the
605 helcionelloid molluscs *Mackinnonia rostrata* and *Pelagiella subangulata* and a wide variety
606 of brachiopods such as *Eoobolus* sp., *Minltonia tuckeri* and *Eodicellomus elkaniiformis*. The
607 tannuoliniid *Micrina etheridgei* is also present in HG1 (Parara Limestone) in Horse Gully.
608 Gravestock et al., (2001, Fig. 4) reported occurrences of *Dailyatia ajax* in the Parara
609 Limestone above the disconformity surface (HG1 and HG9), but none of the specimens are
610 illustrated and re-collection and detailed examination of samples through this interval of the
611 Parara Limestone reveal that *Dailyatia* is completely absent.

612 In the eastern Stansbury Basin, a measured section through the Sellick Hill Formation
613 and Fork Tree Limestone on Fleurieu Peninsula was measured by T. Brougham (2009,
614 unpublished Honours thesis) and by MJB, JBJ, SMJ and GAB (2013, unpublished data). The
615 tommotiid taxon *Sunnaginia imbricata* Missarzhevsky, 1969 was recovered from horizons
616 within Facies E (*sensu* Alexander and Gravestock 1990) in the upper Sellick Hill Formation
617 (Fig. 22). *Sunnaginia* Missarzhevsky, 1969 was widely dispersed during the early Cambrian,
618 with occurrences recorded in Siberia, Mongolia, Avalonian North America, and the United
619 Kingdom (Murdock et al., 2012), but this taxon has not been recovered from the Arrowie
620 Basin. In the upper Sellick Hill Formation, *S. imbricata* co-occurs with *Dailyatia ajax*,
621 *Kulparina rostrata* and a probable new species of *Askepasma*. Typical elements of the *K.*
622 *rostrata* Zone including *D. ajax*, *D. macroptera* and *K. rostrata* occur throughout the
623 overlying Fork Tree Limestone. The presence of taxa indicative of the *K. rostrata* Zone at the
624 top of the Fork Tree Limestone suggests that this unit is older than previously thought and
625 likely correlates with the Hideaway Well and Winnitunny Creek members of the Wilkawillina
626 Limestone in the Arrowie Basin. The lack of trilobites from outcrop in the Fork Tree
627 Limestone supports this correlation. The typically diverse *M. etheridgei* Zone shelly fauna,
628 including the eponym, is absent in the overlying Heatherdale Shale (apart from one specimen
629 collected in a loose nodule; Alexander and Gravestock 1990) (Fig. 22). This may indicate a
630 cryptic disconformity between the Fork Tree Limestone and the Heatherdale Shale (that latter
631 containing *P. janeae* Zone trilobites, e.g., *Atops* Emmons, 1844 (Jago et al., 1984) towards
632 the top of the unit). If this were the case, the *M. etheridgei* Zone would be largely missing in
633 the eastern Stansbury Basin. Alternatively, the deep water slope facies of the Heatherdale
634 Shale may record relatively slow continuous basinal depositional cycles in environments that
635 are devoid of the shelf-dominated shelly fauna that define the *M. etheridgei* Zone.

636

637 6.2.2 Molluscs

638 Early Cambrian molluscs and their biostratigraphic applications have been widely
639 studied (Demidenko, 1999, Parkhaev, 2000, 2001, Parkhaev in Gravestock et al., 2001). In
640 addition to the small shelly fossil scheme, Gravestock et al., (2001) established four informal
641 molluscan zones based mostly on Stansbury Basin material (oldest to youngest): the
642 *Pelagiella subangulata*, *Bemella communis*, *Stenotheca drepanoidea*, and *Pelagiella*
643 *madienesis* zones. Micromolluscan taxa typical of the *M. etheridgei* Zone in the Arrowie
644 Basin include *Pelagiella subangulata*, *Anabarella australis*, *Mackinnonia rostrata* and
645 *Pojetaia runnegari* Jell, 1980 in the Ajax and Wilkawillina limestones. This molluscan
646 assemblage, in particular the occurrence of *P. subangulata* and *M. rostrata*, broadly
647 correlates the *M. etheridgei* Zone with the *Pelagiella subangulata* Zone of Gravestock et al.,
648 (2001) in the Stansbury Basin, though the latter zone is poorly defined.

649 The *Bemella communis* Zone of Gravestock et al., (2001) is very problematic due to
650 the poorly constrained biostratigraphic range and potentially flawed taxonomy of the
651 eponym, thwarting correlation between basins. The stratigraphic range of *B. communis* on
652 Yorke Peninsula is restricted to the lower Parara Limestone, which is approximately
653 equivalent (based on typical *D. odyssei* Zone fauna – see above) with the lower Mernmerna
654 Formation in the Arrowie Basin. However, in the Sellick Hill Formation on Fleurieu
655 Peninsula, the stratigraphic range of *B. communis* ranges below the *Pelagiella subangulata*
656 Zone, preceding the first occurrence of *Sunnaginia imbricata* and *Kulparina rostrata*. This
657 very low stratigraphic occurrence of *Bemella communis* potentially compromises the
658 biostratigraphic utility of this taxon, or at least suggests a detailed revision of this and similar
659 species is required. Furthermore, Gravestock et al., (2001) identified ‘*B. communis*’ in the
660 Mernmerna Formation of the Mulyungarie-2 core in the far eastern part of the Arrowie Basin,
661 but this material was not figured, so the identification cannot be verified.

662 Early Cambrian molluscs are often exceedingly abundant; however, their taxonomy
663 has been plagued by problems of preservation. Steinkerns are very common, but are often not
664 sufficient for classification and therefore should be used with extreme caution in detailed
665 biostratigraphic work. The difficulties associated with early Cambrian mollusc taxonomy and
666 preservation has implications for the widespread use of molluscan taxa such as *P.*
667 *subangulata* as indicators of major stratigraphic boundaries (Peng et al., 2012). Hence, in the
668 current scheme they are relegated to accessory taxa.

669

670 6.2.3 Archaeocyaths

671 Archaeocyaths from Horse Gully on Yorke Peninsula were initially used by Etheridge
672 (1890) to establish a Cambrian age for these limestones in South Australia and were the first
673 group to undergo rigorous biostratigraphic treatment (Walter, 1967). Extensive systematic
674 and biostratigraphic works (Kruse and West 1980; Gravestock, 1984, Zhuravlev and
675 Gravestock, 1994) have established regional archaeocyathan biozones (Peng et al., 2012). Yet
676 there are undoubted taxonomic difficulties. For example, Zhuravlev and Gravestock (1994)
677 demonstrated that a single archaeocyath taxon (*Archaeopharetra irregularis* Taylor, 1910)
678 may be confused with up to six other taxa throughout ontogeny. Identification complications
679 along with high levels of endemism impede their applicability for global-scale
680 biostratigraphic correlation.

681 A biostratigraphic scheme based on archaeocyaths from the Flinders Ranges (i.e.,
682 Wilkawillina Gorge and the Mt. Scott Range) was produced by Gravestock (1984) and later
683 updated with material from Yorke Peninsula (Stansbury Basin) by Zhuravlev and Gravestock
684 (1994). The sections in the Flinders Ranges intersect the lowermost Wilkawillina and Ajax
685 limestones and contain highly diverse archaeocyathan taxa. Gravestock (1984) recognised

686 two major assemblages, Faunal Assemblages I and II and three younger (minor) assemblages,
687 III, IV and V; IV and V are only found in the Mt. Scott Range. Faunal Assemblage II was
688 further subdivided into upper and lower parts (Fig. 22).

689 The oldest assemblage (Faunal Assemblage I) contains a maximum of 10
690 archaeocyath taxa, but only *Copleicyathus cymosus* Gravestock, 1984 and *Warriootacyathus*
691 *wilkawillinensis* Gravestock, 1984 are restricted to this zone and are found in both the
692 Wilkawillina and Ajax Limestone sections. At Wilkawillina Gorge, the incoming of
693 archaeocyaths occurs in the lowermost Mt. Mantell Member, below a distinctive 10 m thick
694 unfossiliferous ooid grainstone. The lower boundary of the *K. rostrata* Zone in the WILK
695 section occurs in the basal Hideaway Well Member, ~20 m above the base of Gravestock's
696 Faunal Assemblage I and so the two zones have ~ 30 m of overlap through the Hideaway
697 Well Member (Fig. 22).

698 Gravestock (1984, p. 3) noted the presence of minor shelly fossils such as a 'large'
699 *Kutorgina* sp. (which is most likely to be *Askepasma saproconcha*), in addition to hyoliths
700 and chancelloriids in Faunal Assemblage 1. Gravestock (1984) does not report any
701 supplementary shelly fossils from his Lower Faunal Assemblage II, but the boundary
702 between Faunal Assemblages I and II is reported to contain a fossiliferous band with
703 *Chancelloria* Walcott, 1920 and the bivalve mollusc "*Fordilla*" Barrande, 1881 (most likely
704 to be *Pojetaia runnegari*, as *Fordilla* is unknown from Australia.

705 The *M. etheridgei* Zone is broadly correlated here to Gravestock's (1984) Lower and
706 Upper Faunal Assemblage I (Fig. 22). The upper boundary of Faunal Assemblage II
707 terminates at the Flinders Unconformity (Wilkawillina Gorge). In Wilkawillina Gorge,
708 *Micrina etheridgei* is noted up to 30 m above the unconformity, but below the Mernmerna
709 Formation (referred to as the Parara Limestone by Gravestock 1984). This section must

710 represent the Second Plain Creek Member of the Wilkawillina Limestone, as it is the only
711 member of the Wilkawillina Limestone deposited post-Flinders Unconformity and it is
712 restricted to the Bunkers Graben (Clarke, 1986b). Gravestock (1984) notes the presence of a
713 variety of brachiopods and *Lapworthella*, suggesting either *M. etheridgei* Zone or perhaps
714 lower *D. odyssei* Zone.

715 Zhuravlev and Gravestock (1994) updated the original archaeocyath scheme of
716 Gravestock (1984) and proposed three formal zones (from oldest to youngest): the
717 *Warriootacyathus wilkawillensis*, *Spirillicyathus tenuis* and *Jugalicyathus tardus* Assemblage
718 Zones. Importantly, these zones were based on Stansbury Basin material, utilising many of
719 the stratigraphic sections that were later used to construct the SSF scheme of Gravestock et
720 al., (2001). The *Warriootacyathus wilkawillensis* Zone can be approximately correlated with
721 the *K. rostrata* Zone, as it is essentially similar to archaeocyath FA I of Gravestock (1984),
722 and was correlated with Daily's Faunal Assemblage 1 (Zhuravlev and Gravestock, 1994).
723 The overlying *Spirillicyathus tenuis* Zone includes archaeocyaths and accessory SSF that
724 correlate it with Gravestock's (1984) Lower Assemblage II and the lowermost parts of
725 Daily's (1956) Faunal Assemblage 2. The youngest zone, the *Jugalicyathus tardus* Zone, is
726 best represented in the Flinders Ranges and is approximately equivalent to Gravestock's
727 (1984) Upper Assemblage II, and slightly overlaps the *A. huoi* trilobite Zone. These younger
728 archaeocyath zones are equivalent to the *M. etheridgei* Zone. The Flinders Unconformity
729 caps the *Jugalicyathus tardus* Zone in the Flinders Ranges. Strata above this zone contain
730 SSF and trilobites such as *Pararaia tatei* (Woodward, 1884) and *P. bunyeroensis* Jell in
731 Bengtson et al., 1990, but no archaeocyath zones are defined (Zhuravlev and Gravestock,
732 1994). Zhuravlev and Gravestock (1994) identify two younger intervals with recognisable
733 archaeocyaths; the *Syringocnema favus* beds and the *Archaeocyathus abacus* beds, which
734 correlate with the *D. odyssei* Zone.

735

736 6.2.4 Acritarchs

737 One of the potential advantages of acritarch biostratigraphy in the Arrowie Basin is
738 that taxa have been retrieved from the lowest siliciclastic strata such as the Uratanna and
739 Parachilna formations, as well as thin shale beds within the Woodendinna Dolostone that do
740 not preserve shelly fossils. However, like archaeocyaths, difficulties with the systematics of
741 acritarchs sometimes confound confident identification of biozones (see discussion by
742 Khomentovsky and Karlova, 1993). Biostratigraphic zonation of early Cambrian acritarchs
743 from South Australia was developed by Zang in Gravestock et al., (2001), Zang et al., (2001),
744 and Zang et al., (2007). Seven acritarch assemblage zones have been developed for the lower
745 Cambrian of South Australia (Zang et al., 2007), ranging from the latest Ediacaran,
746 throughout the lower Cambrian (Terreneuvian–Series 2) to the Series 3, Stage 4–5 boundary.
747 Acritarch Zones 1, 2 and 3 encompass pre-shelly units (Uratanna and Parachilna formations).

748 The acritarch biozonation established by Zang et al., (2007) is a composite scheme
749 based on material from both the Stansbury and Arrowie basins. However, because these
750 coeval basins were deposited under different depositional regimes it is not always easy to
751 recognise and correlate these zones. For example, acritarchs from Assemblage Zone 4
752 (*Skiagia ornata* Zone) are known from the lower Kulpara Limestone (Stansbury Basin),
753 while Assemblage Zone 5 (*Skiagia ciliosa*-*Corollasphaeridium aliquolumum* Zone) is based
754 on material from the Wilkawillina Limestone in the Arrowie Basin. Despite being based on
755 Stansbury Basin material, Assemblage Zone 4 (*Skiagia ornata* Zone) ranges from the upper
756 parts of the Woodendinna Dolostone to the lower Wilkawillina Limestone (*A. huoi* Zone) in
757 the Arrowie Basin (Zang et al., 2007, fig. 18, pg.166), therefore encompassing pre-shelly
758 strata, in addition to the *K. rostrata* Zone and potentially also part of the *M. etheridgei* Zone.

759 The lower and upper boundaries of Acritarch Zone 4 in the Arrowie Basin are poorly
760 constrained due to a lack of detailed sampling in the interval between Zones 4 and 5 (Zang et
761 al. 2007).

762 Acritarch Assemblage Zone 5 (*Skiagia ciliosa*-*Corollasphaeridium aliquolumum*
763 Zone) occurs in the lower Wilkawillina Limestone (Yalkalpo-2 drillcore, 782.7-732.3 m;
764 Zang et al., 2007). Zang et al., (2007) report *Micrina etheridgei*, *Dailyatia* (species not
765 identified) and *A. huoi* from Assemblage Zone 5, therefore correlating it with Faunal
766 Assemblage 2 of Daily (1956), the *Jugalicystus tardus* Zone of Zhuravlev and Gravestock
767 (1994), and the *M. etheridgei* Zone of the present study.

768

769 6.3 Officer Basin

770 In contrast to the richly bioclastic carbonates in the Arrowie Basin, the depositional
771 regime in the Officer Basin during the early Cambrian was dominated by mixed siliciclastics
772 with carbonates and evaporites (Gravestock, 1995). The few early Cambrian shelly fossils
773 described from the Officer Basin are known only from drill cores through the Ouldburra
774 Formation (Gravestock et al., 1997). The Ouldburra Formation and the coeval Relief
775 Sandstone were deposited as part of sequence tracts $\epsilon 1.1$ to $\epsilon 1.3$ that are broadly coincident
776 with the entire Hawker Group in the Arrowie Basin (Gravestock and Hibbert 1991;
777 Gravestock, 1995).

778 The Many-6 drill core (Ouldburra Formation) has yielded cranidia and librigenae of
779 the redlichiid trilobite *Abadiella officerensis* Jago and Dunster, 2002 between 967.7–970.13
780 m depth (Jago et al., 2002a). Additional trilobite fragments were recovered from an interval
781 between 889–1263 m in this core suggesting an age no older Cambrian Stage 3. The oldest

782 fossils in this core are indeterminate sponge spicules (at 1391 m) (Gravestock et al., 1997).
783 Archaeocyath-microbial build-ups also occur in the interval 399–654 m in the Marla-6 drill
784 core which yielded hyoliths, sponge spicules and “ostracods” (probably bradoriids)
785 (Gravestock et al., 1997, p. 94).

786 Poor preservation of most fossil material from the early Cambrian of the Officer
787 Basin makes precise biostratigraphic correlation with the Arrowie Basin difficult. However,
788 the occurrence of *Abadiella officerensis* may correlate with the occurrences of the congeneric
789 *A. huoi* in the Arrowie Basin. Zang et al. (2007) also reported acritarchs from the *Skiagia*
790 *ciliosa-Corollasphaeridium aliquolumum* Zone (acritarch Assemblage Zone 5) from the
791 Manya-6 drillcore, suggesting that this part of the succession may be broadly correlated with
792 the *M. etheridgei* Zone or possibly the *D. odyssei* Zone in the Arrowie Basin.

793

794 6.4 Amadeus Basin, Northern Territory

795 The lower Cambrian Todd River Dolostone in the Amadeus Basin, central Australia is
796 richly fossiliferous (Wells et al., 1967). The unit consists of thinly bedded calcareous
797 sandstones interbedded with thin dolostone beds (Laurie and Shergold, 1985). Early
798 investigation into the shelly fauna from the Todd River Dolostone revealed archaeocyaths
799 associated with “*Micromitra etheridgei*” (= *Micrina etheridgei*) in the lower parts of the unit
800 (Wells et al., 1967). Hyoliths, brachiopods and trilobite fragments were noted in upper
801 stratigraphic levels (Wells et al., 1967; Wells et al., 1970; Laurie, 1986).

802 The Todd River Dolostone type section (and cores 25, 26 and Rodinga 5 drilled by the
803 Bureau of Mineral Resources) produced a rich fauna including *Dailyatia ajax*, *Micrina*
804 *etheridgei*, *Eccentrotheca* sp., cancelloriid spicules, *Sachites* sp., *Thambetolepis* Jell 1981 (=

805 *Sinosachites*) sp., *Edreja* Koneva 1979 (= *Eodicellomus*) sp., *Lingulella* sp., *Pelagiella* sp.,
806 indeterminate trilobites, and other indeterminate shelly fossils (Laurie and Shergold, 1985). A
807 nearby locality (NT600) also produced a well preserved fauna described by Laurie (1986).
808 This material included both mitral and sellate sclerites of *M. etheridgei* (Laurie, 1986). This
809 locality also produced well preserved *Dailyatia* specimens; material figured by Laurie (1986)
810 depicts *D. ajax* sclerites (Laurie, 1986, fig. 6A-I, 7A, C, D, F). The fauna also includes other
811 tomotiids such as *Paterimitra pyramidalis* and *Eccentrotheca* cf. *kanesia* Landing, Nowlan
812 and Fletcher, 1980 (later identified as probable L sclerites of *P. pyramidalis* by Larsson et al.,
813 [2014]), and another kennardiid species, *Kennardia reticulata* Laurie, 1986.

814 A single shell attributed to *Pelagiella* sp. was recovered from NT600 in the Todd
815 River Dolostone, in addition to a brachiopod fauna that includes *Askepasma toddense* Laurie,
816 1986, *Edreja* aff. *distincta* Koneva, 1979 (= *Eodicellomus* sp.) and *Lingulella* (= *Eoobolus*
817 spp.). This combination of taxa, in particular the presence of *Micrina etheridgei*,
818 *Eccentrotheca*, *Askepasma toddense* and additional lingulid brachiopods enables confident
819 correlation between the Todd River Dolostone and the *M. etheridgei* Zone age strata in the
820 Arrowie Basin.

821

822 6.5 Georgina Basin, Northern Territory and Queensland

823 The Red Heart Dolostone in the Georgina Basin is broadly coeval with the Todd
824 River Dolostone in the Amadeus Basin (Laurie and Shergold, 1985). The BMR Hay River
825 11B core intersected 9.8 m of Red Heart Dolostone and yielded a phosphatic shelly fauna that
826 included *Dailyatia ajax*, cancelloriids and *Edreja*-like (= *Eodicellomus* sp.) brachiopods and
827 ?*Ramenta* sp. (Laurie and Shergold, 1985). A diverse fauna, including *Dailyatia ajax*,
828 ?*Tannuolina etheridgei* (= *Micrina etheridgei*), ?*Edreja* sp., *Paterina* sp., *Lingulella* sp.,

829 indeterminate orthid brachiopods, micromolluscs such as *Yochelcionella* sp., hyoliths,
830 echinoderm fragments and cancelloriids, was also recovered from the Errarra Formation
831 (Mopunga), which was synonymised with the Red Heart Dolostone (Laurie and Shergold,
832 1985; Dunster et al., 2007). This shelly assemblage, particularly the occurrence of *M.*
833 *etheridgei*, correlates the Red Heart Dolostone with strata encompassing the *M. etheridgei*
834 Zone in the Arrowie Basin.

835

836 7. CORRELATION OUTSIDE AUSTRALIA

837 The difficulties surrounding global correlation of lower Cambrian pre-trilobitic strata
838 based on SSF occurrences have been well documented (see Steiner et al., 2004, 2007;
839 Landing et al., 2013), and are largely due to faunal provincialism and facies dependence of
840 many key taxa. Therefore, high resolution correlation of this scheme outside of East
841 Gondwana is problematic. The aim of this contribution has been to establish a workable
842 regional biostratigraphic scheme. Various faunal elements (mostly at genus level) from the
843 South Australian shelly biozones have been identified that link the successions most closely
844 to strata in China (Fig. 23).

845

846 7.1 *Kulparina rostrata* Zone

847 The low diversity fauna of the *K. rostrata* Zone are highly endemic, which limits
848 correlation outside of East Gondwana. However, in the Stansbury Basin, *Kulparina rostrata*
849 partially overlaps with the tomotiid *Sunnaginia imbricata* over a relatively short interval
850 (2.5 m) in Facies D of the upper Sellick Hill Formation (unpublished data), providing
851 potential global correlation for the lower part of the *K. rostrata* Zone. *Sunnaginia* has a wide

852 distribution in the early Cambrian, with previous reports from lower Cambrian strata in
853 England, Siberia, Avalonian North America and Mongolia (see Murdock et al., 2012 and
854 references therein). However, *Sunnaginia* has not been recovered from the Arrowie Basin,
855 possibly due to a lack of suitable facies.

856

857 7.2 *Micrina etheridgei* Zone

858 In China, the *S. flabelliformis*-*T. zhangwentangi* Assemblage Zone is succeeded by
859 the *Parabadiella huoi* trilobite Zone which correlates directly with the *A. huoi* Zone in South
860 Australia (Jago et al., 2002b; Paterson and Brock, 2007). Whilst there is continued debate
861 about the generic assignment of this species (see Landing et al., 2013 for discussion), there is
862 general agreement that *A. huoi* and *P. huoi* are conspecific. Hence, there is strong correlation
863 between the trilobitic upper part of the *M. etheridgei* Zone and the *P. huoi* zone in China.
864 Traditionally, the *A. huoi* Zone is considered to be younger than the *Profallotaspis* and
865 *Fallotaspis* zones in Siberia (see Peng et al., 2012, fig. 19.3; Landing et al., 2013, fig. 4),
866 though Yuan et al., (2011) indicated the *Parabadiella* Zone in China can be interpreted as
867 time-equivalent to the *Eofallotaspis* Zone in Morocco and the *Profallotaspis jakutensis* Zone
868 in Siberia. The correlation chart of Landing et al., (2013, fig. 4) indicates *Fallotaspis bondoni*
869 (Neltner and Pöctey 1950) from southern Morocco is late Issendalenian (*Choubertella*-
870 *Daguinaspis* Zones) in age, which is ~519 Ma (Peng et al., 2012, fig. 19.11). The *Abadiella*
871 *huoi* (= *Parabadiella*) Zone is lower Nangaoan (= upper Atdabanian, *sensu* Landing et al.,
872 2013), which is therefore slightly younger (ca. 518 Ma) (Peng et al., 2012, fig. 19.11).
873 Therefore, *Abadiella* and *Fallotaspis* Hupe, 1953 may well have been contemporaneous, but
874 occurring in different trilobite provinces (see Fig. 23).

875 In South China, the first appearance of *Micrina xiaotanensis* Li and Xiao, 2004
876 overlaps with the last appearance of *Sinosachites flabelliformis* He, 1980 and *Lapworthella*
877 *rete* Yue, 1987 in the lower Yuanshan Formation (Li and Xiao 2004). The last occurrence of
878 *L. rete* defines the upper boundary of the *S. flabelliformis*-*T. zhangwentangi* Assemblage
879 Zone in South China (Steiner et al., 2007). Thus, co-occurrence of *Micrina*, *Lapworthella* and
880 halkieriid sclerites (likely to be *Sinosachites*) in the *M. etheridgei* Zone can be correlated with
881 the upper part of the *S. flabelliformis*-*T. zhangwentangi* Assemblage Zone in China.

882 *Lapworthella rete* and *Conotheca brevica* Qian, Xie and He, 2001 have been reported
883 from the Marcory Formation, southern France, which Devaere et al., (2014a) correlates with
884 the *S. flabelliformis*-*T. zhangwentangi* Assemblage Zone in China based on co-occurrence of
885 the taxa in both localities. Hyoliths are abundant in the AJX-M section which includes taxa
886 such as *Triplicatella disdoma* Conway Morris in Bengtson et al., 1990 (Skovsted et al.,
887 2014b), and *Cupithecra holocyclata* Bengtson in Bengtson et al., 1990 (Skovsted et al., 2016),
888 and probable conothecids. They co-occur with *Lapworthella* in the *M. etheridgei* Zone
889 providing a temporal link with the Marcory Formation, southern France and the *S.*
890 *flabelliformis*-*T. zhangwentangi* Assemblage Zone in China.

891 Some brachiopods that first appear in the *M. etheridgei* Zone also have a global
892 distribution. *Eoobolus*, for example, is widely dispersed, but this genus is currently poorly
893 defined and probably represents a “wastebasket” taxon that is very long ranging, which
894 currently limits biostratigraphic application (Ushatinskaya, 2012). In addition, *Askepasma*
895 *transversalis* Peng, Zhao, Qin, Yan and Ma, 2010 from the lower Cambrian Balang
896 Formation, eastern Guizhou is the only occurrence of the genus outside Australia (Peng et al.,
897 2010). However, in the Balang Formation, this taxon co-occurs with *Redlichia chinensis*
898 Walcott, 1905. In Australia, *Redlichia* occurs in younger strata (Series 2, late Stage 4)
899 (Laurie, 2006), and hence is unlikely to correlate with the zones described herein.

900 Furthermore, the illustrated specimens have a more prominent pedicle beak than either
901 *Askepasma toddense* or *A. saproconcha* and do not display the reticulate microornament
902 diagnostic of the genus, leaving identification and correlation of these specimens in doubt.

903 Bradoriid fauna have often been used to distinguish Cambrian biogeographic
904 provinces (Siveter and Williams, 1997; Melnikova et al., 1997; Williams and Siveter, 1998;
905 Hou et al., 2002; Williams et al., 2007; Topper et al., 2011b). Australian bradoriid
906 assemblages bear close taxonomic similarities (at the genus level) with those from South
907 China (Topper et al., 2007, 2011b; Betts et al., 2014), though genera in Australia are typically
908 correlated to older strata. For example, *Jiucunella* was thought to be endemic to China until
909 the recent description of *Jiucunella phaselo* from the Arrowie Basin (Betts et al., 2014).
910 *Jiucunella phaselo* is restricted to the *M. etheridgei* Zone in South Australia. In South
911 China, the morphologically similar *Jiucunella paulaula* is restricted to the slightly younger
912 *Eoredlichia-Wutingaspis* Zone in the Qiongzhusian Formation in Chengjiang County,
913 Yunnan (Hou & Bergström, 1991; Hou et al., 2002).

914 Similarly, *Jixinlingella* was only known from the lower Cambrian Shuijingtuo
915 Formation (*Eoredlichia-Wutingaspis* Zone), Shaanxi, central China (Lee 1975; Zhang 2007)
916 before *Jixinlingella daimonikoa* was described by Betts et al. (2014) from the *M. etheridgei*
917 Zone. In addition, *Neokunmingella* cf. *minuta* ranges from the *Eoredlichia-Wutingaspis* Zone
918 in the Qiongzhusi Formation to the *Palaeolenus* Zone in the Canglangpu Formation in
919 South China (Hou et al., 2002). *Neokunmingella shuensis* is also recorded from the
920 *Eoredlichia-Wutingaspis* Zone in Southern China (Zhang, 2007). In the Arrowie Basin,
921 *Neokunmingella moroensis* appears to represent an older occurrence, being restricted to the
922 *M. etheridgei* Zone in the MORO and MOG sections.

923

924 8. CONCLUSION

925 This new biostratigraphic scheme applies the widely adopted methodology of defining
926 only lower boundaries based on first occurrences of diagnostic fossils in a stratigraphic
927 section, which simplifies both the definitions and visual representation of the zones.
928 Unrecognised time-breaks between zones (e.g. boundary between the *M. etheridgei* and *D.*
929 *odyssei* zones) can confound accurate identification of biozone boundaries, frustrating
930 correlation at regional (and global) scale. This is further supports the need for integrating
931 multi-proxy datasets, particularly biostratigraphy and chemostratigraphy to calibrate and
932 circumvent shortcomings of relative dating methods.

933 Definition of internationally acceptable boundaries for lower Cambrian
934 chronostratigraphic subdivisions remains unresolved, especially the base of Stages 2, 3 and 4.
935 Many previous biostratigraphic schemes for Australia have utilised Siberian stages (e.g.
936 Kruse et al., 2009) or the depositional sequence sets of Gravestock and Cowley (1995).
937 Resolving this issue ultimately hinges on the resolution of biostratigraphic ranges of shelly
938 fauna through regional, basin-scale sequences.

939 Absence of trilobites below the Cambrian Series 2, Stage 3 *Abadiella huoi* trilobite
940 Zone means that other faunal groups must be employed to fill this biostratigraphic gap in East
941 Gondwana. Schemes based on acritarchs (Zang in Gravestock et al., 2001; Zang 2001; Zang
942 et al., 2007), archaeocyaths (Gravestock, 1984; Zhuravlev and Gravestock, 1994) and
943 ichnofossils (Droser et al., 1999) have been used with varying success. Biozones based on
944 shelly fossils have great potential to fill the pre-trilobitic gap in Australia and contribute
945 meaningfully to lower Cambrian regional and global correlation.

946 Measured sections have yielded abundant shelly fossils from the Wilkawillina,
947 Wirrapowie and Ajax limestones, the biostratigraphic ranges of which are predictable and

948 repeatable across the basin. This has resulted in the establishment of three new biozones (in
949 ascending order): the *Kulparina rostrata* Zone, *Micrina etheridgei* Zone, and the *Dailyatia*
950 *odyssei* Zone. The *D. odyssei* Zone is associated predominantly with the Mernmerna
951 Formation (and equivalent strata) and will be documented in greater detail in a subsequent
952 paper. These zones intersect the fossiliferous part of the Hawker Group in the Arrowie Basin,
953 South Australia and allow robust correlation both within the basin and with coeval
954 depocentres such as the Stansbury, Amadeus, Georgina and Officer basins. The endemic
955 nature of many of the taxa utilised in this scheme, restrict global correlation. However, faunal
956 correlation with China is enabled through occurrences of several cosmopolitan shelly fossil
957 genera (and species), indicating that the *K. rostrata* and *M. etheridgei* zones correlate with
958 the Meishucunian *S. flabelliformis*-*T. zhangwengtangi* Assemblage Zone in China. Therefore,
959 the Australian zones range from the upper Terreneuvian Series, Stage 2 to Series 2, Stage 3.

960

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974

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1534

1535 Captions

1536 Fig. 1. Extent of Arrowie Basin, South Australia showing Cambrian outcrop and locations of
1537 measured sections.

1538 Fig. 2. AJX-M stratigraphic section through the Ajax Limestone in Mt. Scott, north-western
1539 Flinders Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone and
1540 the *Dailyatia odyseii* Zone are shown. AJX-M has trilobite control; extent of the *Abadiella*
1541 *huoi* and *Pararaia tatei* Zones are shown. Abundance data is given in Appendix 1.

1542 Fig. 3. AJX-N stratigraphic section through the Ajax Limestone in Mt. Scott, north-western
1543 Flinders Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone are
1544 shown. Abundance data is given in Appendix 2.

1545 Fig. 4. MORO stratigraphic section through the Parachilna Formation, Woodendinna
1546 Dolostone and Wilkawillina and Wirrapowie limestones in the Arrowie Syncline, northern
1547 Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1548 *Micrina etheridgei* Zone are shown. Abundance data is given in Appendix 3.

1549 Fig. 5. MOG stratigraphic section through the Wirrapowie and Wilkawillina limestones,
1550 Mernmerna Formation and Nepabunna Siltstone in the Arrowie Syncline, northern Flinders
1551 Ranges. Ranges of key shelly fossil taxa through the *Micrina etheridgei* Zone and the

1552 *Dailyatia odyssei* Zone are shown. Note the Flinders Unconformity is not developed in the
1553 Arrowie Syncline and the succession is largely continuous between the Wirrapowie
1554 Limestone and the Mernmerna Formation. Abundance data is given in Appendix 4.

1555 Fig. 6. WAR stratigraphic section through the Wirrapowie Limestone in the central Flinders
1556 Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone are shown. Abundance
1557 data is given in Appendix 5.

1558 Fig. 7. BALC stratigraphic section through the Parachilna Formation, Wilkawillina
1559 Limestone and the Billy Creek Formation in the Bunkers Range, central Flinders Ranges. The
1560 Flinders Unconformity represents erosion of the upper Winnitunny Creek Member and non-
1561 deposition of the entire Mernmerna Formation, hence the *D. odyssei* Zone is not present in
1562 the BALC section. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1563 *Micrina etheridgei* Zone. Abundance data is given in Appendix 6.

1564 Fig. 8. MMT stratigraphic section through the Wilkawillina Limestone and Mernmerna
1565 Formation in the Bunkers Range, central Flinders Ranges. The Flinders Unconformity (FU)
1566 occurs at horizon MMT/295.5 where the Third Plain Creek Member of the Mernmerna
1567 Formation (*P. bunyeroensis* trilobite zone) lies unconformably on the Winnitunny Creek
1568 Member of the Wilkawillina Limestone. Hence, the Six Mile Bore and Linns Springs
1569 members of the Mernmerna Formation are missing. The *D. odyssei* Zone is indicated by the
1570 occurrence of *Stoibostrombus crenulatus* but does not represent the true base of the zone due
1571 to the FU. Abundance data is given in Appendix 7.

1572 Fig. 9. WILK (Wilkawillina Limestone type section) stratigraphic section through the
1573 Woodendinna Dolostone, Wilkawillina Limestone and Mernmerna Formation in the Bunkers
1574 Graben, central Flinders Ranges. The Flinders Unconformity (FU) in the WILK section
1575 represents a time break between the Winnitunny Creek and Second Plain Creek members of

1576 the Wilkawillina Limestone. The true base of the *D. odyssei* Zone is difficult to ascertain due
1577 to the unknown time gap represented by the “reddened horizon”. Additional sampling
1578 between the horizons immediately above and below the FU will clarify boundaries.

1579 Abundance data is given in Appendix 8.

1580 Fig. 10. 10MS-W stratigraphic section through the Parachilna Formation, Wilkawillina
1581 Limestone and the Mernmerna Formation in the south-eastern Bunkers Graben, central
1582 Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and the
1583 *Micrina etheridgei* Zone are shown. Abundance data is given in Appendix 9.

1584 Fig. 11. CR1 stratigraphic section through the Wirrapowie Limestone in the Chase Range,
1585 southern Flinders Ranges. Ranges of key shelly fossil taxa through the *K. rostrata* Zone and
1586 the *M. etheridgei* Zone are shown. Abundance data is given in Appendix 10.

1587 Fig. 12. Correlation of all stratigraphic sections within the Arrowie Basin based on
1588 stratigraphic extent of the *K. rostrata* Zone, the *Micrina etheridgei* Zone and the *Dailyatia*
1589 *odyssei* Zone.

1590 Fig. 13. Shelly taxa typical of the *K. rostrata* Zone; *Askepasma saproconcha*, *Kulparina*
1591 *rostrata* and *Paterimitra pyramidalis*. A-G, *A. saproconcha* all from Wirrapowie Limestone.
1592 A, dorsal valve, CR1/108.0, SAM P53154. B, ventral valve, CR1/129.0, SAM P53155. C,
1593 ventral valve CR1/108.0, SAM P53156. D, dorsal valve CR1/114.0, SAM P53157. E, dorsal
1594 valve CR1/141.0, SAM P53158. F, ventral valve CR1/129.0, SAM P 53159. G, dorsal valve
1595 CR1/129.0, SAM P53160. H-N, Q, *K. rostrata* all from Hideaway Well Member (HWM) of
1596 the Wilkawillina Limestone. H, MMT/65.7, SAM P53161. I, MMT/76.6, SAM P53162. J,
1597 MMT/44.3, SAM P53163. K, MMT/71.9, SAM P53164. L, MMT/76.6, SAM P53165. M,
1598 MMT/76.6, SAM P53166. N, MMT/76.6, SAM P53167. Q, MMT/76.6, SAM P53170. O, P,
1599 R-V, *Paterimitra pyramidalis*. O and S, MMT/20.0, Wilkawillina Limestone (HWM), SAM

1600 P53168. P, MORO/933.2, Wirrapowie Limestone, SAM P53169. R, MORO/Spot Locality
1601 Aa (Betts et al., 2014), Wilkawillina Limestone (HWM), SAM P53171. T, MMT/126.5,
1602 Winnitunny Creek Member (WTCM) of the Wilkawillina Limestone, SAM P53172. U,
1603 MORO/881.6, Wilkawillina Limestone (WTCM), SAM P53173. V, MORO/730.0,
1604 Wilkawillina Limestone (HWM), SAM P53174.

1605 Fig. 14. *Dailyatia* species occurring in the *K. rostrata* Zone and the *M. etheridgei* Zone. A-G,
1606 *D. ajax*. A, A1 sclerite, MORO/1081.0, Wirrapowie Limestone, SAM P53175. B, B1 sclerite,
1607 MORO/881.6, SAM P53176. C, B2 sclerite, MORO/1081.0, Wirrapowie Limestone, SAM
1608 P53177. D, C1 sclerite, MOG/204.5, Wirrapowie Limestone, SAM P53178. E, reticulate
1609 microornament of *D. ajax*, MMT/237.5, Winnitunny Creek Member (WTCM) of the
1610 Wilkawillina Limestone, SAM P53179. F, B1 sclerite, MORO/1081, Wirrapowie Limestone,
1611 SAM P53180. G, C1 sclerite, MORO/589.0, Wilkawillina Limestone Hideaway Well
1612 Member (HWM), SAM P53181. H-K, *D. macroptera*. H, A1 sclerite, MORO/1081.0,
1613 Wirrapowie Limestone, SAM P53182. I, B sclerite, MORO/1043.0, Wirrapowie Limestone,
1614 SAM P53183. J, C1 sclerite, MORO/633.0, Wilkawillina Limestone (HWM), SAM P53184.
1615 K, C1 sclerite, MOG/201.0, Wirrapowie Limestone, SAM P53185. L-O, *D. helica*. L, A1
1616 sclerite, MORO/933.2, Wirrapowie Limestone, SAM P53186. M, B sclerite, MMT/237.5,
1617 Wilkawillina Limestone (WTCM), SAM P53187. N, C1 sclerite, MMT/195.5, Wilkawillina
1618 Limestone (WTCM), SAM P53188. O, C2a sclerite, MMT/243.1, Wilkawillina Limestone
1619 (WTCM), SAM P53189. P-S, *D. bacata*. P, A2 sclerite, MMT/109.0, Wilkawillina
1620 Limestone (WTCM), SAM P53190. Q, C2 sclerite, MMT/126.5, Wilkawillina Limestone
1621 (WTCM), SAM P53191. R, C1 sclerite, MMT/240.0, Wilkawillina Limestone (WTCM),
1622 SAM P53192. S, C1 sclerite, AJX-N/275.0, Ajax Limestone, SAM P53193.

1623 Fig. 15. *Eccentrotheca helenia* and *Micrina etheridgei* typical of the *M. etheridgei* Zone. A-I,
1624 *E. helenia*. A, MOG/210.0, Winnitunny Creek Member (WTCM) of the Wilkawillina

1625 Limestone, SAM P53194. B, D, MMT/237.5, Wilkawillina Limestone (WTCM), SAM
1626 P53195, SAM P53197. C, MORO/881.6, Wilkawillina Limestone (WTCM), SAM P53196.
1627 E, MMT/231.0, Wilkawillina Limestone (WTCM), SAM P53198. F-H, MOG/42.8,
1628 Wirrapowie Limestone, SAM P53199, SAM P53200, SAM P53201. I, MMT/237.5,
1629 Wilkawillina Limestone (WTCM), SAM P53202. J-P, *Micrina etheridgei*. J, sellate sclerite,
1630 MORO/Spot Locality F, Wirrapowie Limestone (Betts 2012), SAM P53203. K, sellate
1631 sclerite, MOG/170.0, Wirrapowie Limestone, SAM P53204. L, sellate sclerite, MOG/190.0,
1632 Wirrapowie Limestone, SAM P53205. M, N and P, mitral sclerites, MORO/Spot Locality F,
1633 SAM P53206, SAM P53207, SAM P53209. O, mitral sclerite, MMT/87.0, Wilkawillina
1634 Limestone (WTCM), SAM P53208.

1635 Fig. 16. *Askepasma toddense* and *Eoobolus* sp. from the *M. etheridgei* and *D. odyssei* Zones.
1636 A-H, *A. toddense*. A, exterior of dorsal valve, MMT/138.2, Winnitunny Creek Member
1637 (WTCM) of the Wilkawillina Limestone, SAM P53210. B(G) and C, exterior of dorsal valves
1638 showing four-lobed larval shell, MOG/912.0, Mernmerna Formation, SAM P53211, SAM
1639 P53212. D, interior of ventral valve, MOG/17.0, Wirrapowie Limestone, SAM P53213. E,
1640 interior of dorsal valve, MOG/10.5, Wirrapowie Limestone, SAM P53214. F, ventral valve,
1641 MORO/Spot Locality Aa (Betts et al., 2014), Hideaway Well Member of the Wilkawillina
1642 Limestone, SAM P53215. H, external reticulate microornament, MORO/1081.0, Wirrapowie
1643 Limestone, SAM P53216. I-U, *Eoobolus* sp. I (ventral valve) and N (dorsal valve)
1644 MOG/240.0, Winnitunny Creek Member (WTCM) of the Wilkawillina Limestone, SAM
1645 P53217, SAM P53222. J, MOG/223.0, Wilkawillina Limestone (WTCM), SAM P53218. K
1646 and O (ventral valves) MOG/404.0, Mernmerna Formation, SAM P53219, SAM P53223. L,
1647 dorsal valve, MOG/667.4, Mernmerna Formation, SAM P53220. M (dorsal valve) and P
1648 (ventral valve) MOG/382.2, Mernmerna Formation, SAM P53221, SAM P53224. Q, AJAX-
1649 M/267.5, Ajax Limestone, SAM P53225. R and T, *Eoobolus* sp. dorsal valve with pustulose

1650 microornament AJX-M/274.0, Ajax Limestone, SAM P53226. S and U, *Eoobolus* sp. dorsal
1651 valve with pustulose microornament AJX-M/368.0, Ajax Limestone, SAM P53227.

1652 Fig. 17. *Karathele* (= *Schizopholis*) *yorkensis*, *Eodicellomus elkaniformiis*, *Minlatonia tuckeri*
1653 and *Kyrshabactella davidii* from the *M. etheridgei* Zone and the *D. odyssei* Zone. A-H, *K.*
1654 *yorkensis* all except B from the Ajax Limestone. A, C-E from AJX-M/387.0. A, ventral
1655 valve, SAM P53228. C, dorsal valve SAM P53230. D, ventral valve SAM P53231. E, ventral
1656 valve SAM P53232. B, dorsal valve from MOG/551.5, Mernmerna Formation, SAM P53229.
1657 F, ventral valve, AJX-M/368.0, SAM P53233. G, dorsal valve, AJX-M/388.0, SAM P53234.
1658 H, external microornament, AJX-M/267.5, SAM P53235. I-P, *Eodicellomus elkaniformiis*,
1659 and *Minlatonia tuckeri* all from the Ajax Limestone. I (ventral valve) and J (articulated), *E.*
1660 *elkaniformiis*, AJX-M/387.0, SAM P53236, SAM P53237. K, *E. elkaniformiis* dorsal valve,
1661 AJX-M/266.0, SAM P53238. L, *E. elkaniformiis* dorsal valve, AJX-M/357.5, SAM P53239.
1662 M, *E. elkaniformiis* ventral valve, AJX-M/305.0, SAM P53240. N, *M. tuckeri* ventral valve
1663 interior, AJX-M/217.5, SAM P53241. O, *M. tuckeri* dorsal valve exterior, AJX-M/256.0,
1664 SAM P53242. P, *M. tuckeri* dorsal valve larval shell, AJX-M/263.0, SAM P53243. Q-T, *K.*
1665 *davidii* all ventral valves. Q and T, MMT/240.0, Winnitunny Creek Member (WTCM) of the
1666 Wilkawillina Limestone, SAM P53224, SAM P53247. R, MMT/225.8, Wilkawillina
1667 Limestone (WTCM), SAM P53245. S, BALC/540.0, Wilkawillina Limestone (WTCM),
1668 SAM P53246.

1669 Fig. 18. Molluscan fauna from the *M. etheridgei* Zone and the *D. odyssei* Zone. *Pelagiella*
1670 steinkerns (A-D, G) and phosphatised coatings (E, F, H). A, MOG/42.8, Wirrapowie
1671 Limestone, SAM P53248. B, MOG/15.0, Wirrapowie Limestone, SAM P53249. C,
1672 MOG/264.7, Winnitunny Creek Member (WTCM) of the Wilkawillina Limestone SAM
1673 P53250. D, MORO/829.7, Wilkawillina Limestone (WTCM), SAM P53251. E, silicified
1674 shell, MMT/265.1, Wilkawillina Limestone (WTCM), SAM P53252. F and H, phosphatised

1675 shells, MOG/0.0, Wirrapowie Limestone, SAM P53253, SAM P53255. G, BALC/580.0,
1676 Wilkawillina Limestone (WTCM), SAM P53254. I-M, *Anabarella steinkerns* (L and M with
1677 phosphatised coating). I and J, MORO/Spot Locality C (Betts *et al.*, 2014), Wilkawillina
1678 Limestone (WTCM), SAM P53256, SAM P53257. K, MOG/42.8, Wirrapowie Limestone,
1679 SAM P53258. L and M steinkerns with shell, MOG/264.7, MOG/210.0, Wilkawillina
1680 Limestone (WTCM), SAM P53259, SAM P53260. N-U, *Mackinnonia steinkerns* (O with
1681 silicified shell material). N, R and T, MOG/264.7, Wilkawillina Limestone (WTCM), SAM
1682 P53261, SAM P53264, SAM P53266. O, steinkern with silicified shell, AJX-M/266.0, Ajax
1683 Limestone, SAM P50906. P, MOG/210.0, Wilkawillina Limestone (WTCM), SAM P53262.
1684 Q, close up of ornament on steinkern, AJX-M/271.3, Ajax Limestone, SAM P53263. S,
1685 MOG/247.0, Wilkawillina Limestone (WTCM), SAM P53265. U, MMT/138.2, Wilkawillina
1686 Limestone (WTCM), SAM P53267.

1687 Fig. 19. Bradoriid fauna from the *M. etheridgei* Zone. A-D, *Jiucunella phaseloia*, all from
1688 Wirrapowie Limestone. A, left shield, MOG/0.0, SAM P53268. B, shields split along dorsal
1689 fold, MOG/33.3, SAM P51221. C, conjoined specimen with wide ventral gape, MOG/0.0,
1690 SAM P51222. D, right shield, MOG/31.2, SAM P53269. E-H, *Sinskolutella cuspidata*, all
1691 from MORO/933.2, Wirrapowie Limestone. E and F, left shield with well-preserved external
1692 microornament, SAM P48677. G, left shield, SAM P48671. H, left shield, SAM P48672. I-L,
1693 *Neokunmingella moroensis*, all from the Wirrapowie Limestone. I, left shield, MOG/10.0,
1694 SAM P51225. J, internal view of right shield, MOG/10.0, SAM P51226. K, conjoined
1695 specimen, MOG/10.0, SAM P51227. L, close up of external microornament, MOG/0.0, SAM
1696 P53270. M-R, *Mongolitubulus anthelios* shields, and spines. M, *M. anthelios* shield with
1697 central spine from MORO/881.6, from the Winnitunny Creek Member (WTCM) of the
1698 Wilkawillina Limestone, SAM P48700. N, *M. anthelios* shield with central spine missing
1699 from MOG/10.5, Wirrapowie Limestone, SAM P53275. O, R, *M. anthelios* spine showing

1700 rhomboid scales, MOG/114.1, Wirrapowie Limestone, SAM P53276. P, *M. anthelios* spine,
1701 MORO/889.0, Wilkawillina Limestone (WTCM), SAM P48697. Q, *M. anthelios* spine,
1702 MOG/15.0, Wirrapowie Limestone, SAM P53277. S, T, *Jixinlingella daimonikoa*, conjoined
1703 shields (holotype) MORO/1043.0, Wirrapowie Limestone, SAM P48683. U, *J. daimonikoa*
1704 left shield, MORO/1043.0, Wirrapowie Limestone, SAM P48684.

1705 Fig. 20. Bradoriid fauna from the *M. etheridgei* Zone and the *D. odyssei* Zone. A-D,
1706 *Parahoulongdonella bashanensis*. A-B, left shield, CR1/500.0, Wirrapowie Limestone SAM
1707 P53278. C- D, left shield, RC/102.0, Wirrapowie Limestone, SAM P53282. E-F, *Quadricona*
1708 *madonnae*, both from the Wirrapowie Limestone. E, conjoined specimen, RC/252.9, SAM
1709 P53283. F, right shield, RC/252.9, SAM P53285. G-H, *Albrunnicola bengtsoni*,
1710 BALC/580.0, Winnitiny Creek Member (WTCM) of the Wilkawillina Limestone, SAM
1711 P53280. I, *Euzepaera* sp. A., ER9/53.5, Wirrapowie Limestone. J-K, *Mongolitubulus* sp.,
1712 CR1/589.7, Wirrapowie Limestone, SAM P53281. L(O) and P, *Spinospitella coronata* all
1713 from BALC/580.0, Wilkawillina Limestone (WTCM). L, close up of spine tip from (O). O,
1714 broken spine, SAM P53284. P, broken spine with abraded ornament, SAM P53287. M-N, *S.*
1715 *coronata* shield fragment from ER9/0.0, Wirrapowie Limestone, SAM P44806.

1716 Fig. 21. Typical shelly fauna associated with the *Dailyatia odyssei* Zone. A-G and K,
1717 *Lapworthella fasciculata*. A, MOG/264.7, Winnitiny Creek Member (WTCM) of the
1718 Wilkawillina Limestone, SAM P53292. B and K, MOG/912.0, Mernmerna Formation, SAM
1719 P53293. C, AJX-N/382.4, Ajax Limestone, SAM P53294. D, MMT/268.0, Wilkawillina
1720 Limestone (WTCM), SAM P53295. E, MOG/905.4, Mernmerna Formation, SAM P53296. F,
1721 MMT/268.0, Wilkawillina Limestone (WTCM), SAM P53297. G, MMT/265.1, Wilkawillina
1722 Limestone (WTCM), SAM P53298. H-J and L, *Stoibostrombus crenulatus*. H and L,
1723 MOG/912.0, Mernmerna Formation, SAM P53299. I and J, MOG/905.4, Mernmerna
1724 Formation, SAM P53300, SAM P53301. M-O, *Dailyatia odyssei*, all C1 sclerites from the

1725 Second Plain Creek Member of the Wilkawillina Limestone (WILK Type Section). M,
1726 WILK/S, SAM P53302. N and O, WILK/Q, SAM P53303, SAM P53304. P- S, Obolidae
1727 gen. et. sp. indet. all from AJX-M/357.0 in the Ajax Limestone. P, ventral valve, SAM
1728 P53305. Q, ventral valve, SAM P53306. R and S, dorsal valve, SAM P53307. T-V, sclerites
1729 from *Microdictyon* sp., all from the Winnitunny Creek Member of the Wilkawillina
1730 Limestone. T and U, MOG/215.0, SAM P53308. V, MOG/231.2, SAM P53309. W,
1731 *Mongolodus* sp. from COOP/RS377 in the Second Plain Creek Member of the Wilkawillina
1732 Limestone, SAM P53310. X, *Protohertzina* sp., from MOG/551.5 in the Mermerna
1733 Formation, SAM P53311.

1734 Fig. 22. Regional correlation of the *K. rostrata*, *M. etheridgei* and the *Dailyatia odyseii*
1735 zones. The assemblages can be confidently correlated between the Arrowie Basin and the
1736 western Stansbury Basin (Yorke Peninsula), eastern Stansbury Basin (Fleurieu Peninsula)
1737 based on co-occurrence of key fauna. Position of previous schemes utilising shelly fossils
1738 (Daily 1956) and archaeocyaths (Gravestock 1984) are also included. Note uncertainty of
1739 shelly fossil zonation in the Heatherdale Shale is due to lack of fauna. Dashed lines indicate
1740 boundaries are uncertain. Undulating lines indicate unconformities.

1741 Fig. 23. Correlation of the *K. rostrata* and *M. etheridgei* zones with South China utilising key
1742 cosmopolitan genera. Figure adapted from Steiner et al (2007, figs 11 and 12); Yuan et al
1743 (2011, table 2); Peng et al. (2012, fig. 19.11); Yang et al (2013, fig. 5). Further global
1744 correlation is hindered by lack of cosmopolitan species in the *K. rostrata* and *M. etheridgei*
1745 zones. Dashed lines indicate boundaries are uncertain. Undulating lines indicate
1746 unconformities.

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1782 **Jim Jago** is currently Adjunct Professor within the School of Natural and Built
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1793 **Sarah M. Jacquet** is a PhD student in the Department of Biological Sciences, Macquarie
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1798 understand the early evolution and radiation of the Mollusca from the lower Cambrian of East
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1803 **Christian B. Skovsted** is Senior Curator of invertebrate palaeontology at the Swedish
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1824 **Glenn A. Brock** is an Associate Professor of Palaeobiology in the Department of Biological
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