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► **To cite this version:**

Junyu Wan, Aihua Yuan, S. Crasquin, Haishui Jiang, Hao Yang, et al.. High-resolution variation of ostracod assemblages from microbialites near the Permian-Triassic boundary at Zuodeng, Guangxi, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 2019, 535, pp.109349. 10.1016/j.palaeo.2019.109349 . hal-03019848

HAL Id: hal-03019848

<https://hal.science/hal-03019848>

Submitted on 29 Sep 2021

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1 **High-resolution variation of ostracod assemblages from microbialites near**
2 **the Permian-Triassic boundary at Zuodeng, Guangxi, South China**

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13

14 **Abstract**

15 After the end-Permian mass extinction (EPME), the marine environment was considered
16 extremely toxic, which was mainly due to the anoxic and high-temperature conditions and
17 ocean acidification; thus, the ecosystem contained few organisms. This paper describes a new
18 ostracod fauna from the microbialites-bearing Permian-Triassic (P-Tr) strata at Zuodeng,
19 Guangxi, China. One thousand and seventy ostracod specimens were extracted from forty-eight
20 samples. Fifty-three species belonging to fourteen genera were identified. Ostracods, primarily
21 from the Family Bairdiidae, were extremely abundant in the microbialites, which suggests that
22 the ostracods were opportunists able to survive within this special microbial ecosystem with

23 sufficient food and scarce competitors and predators rather than undergoing a rapid and early
24 recovery after the end-Permian mass extinction event. Ostracods present simultaneous
25 Paleozoic and Meso-Cenozoic affinities. The similarities and differences among the ostracod
26 faunas in the microbialites at the P-Tr boundary sections around the Paleo-Tethys indicate that
27 there was a long-distance dispersion of ostracods. However, the faunas maintained endemism
28 at the specific level. Previous studies have regarded microbialites as whole units, and it is
29 difficult to detect environmental changes within a microbialite interval based on
30 paleoecological groups of (super) families. In this study, high-density sampling was applied to
31 identify changes of abundance, diversity, and composition of assemblages of ostracods. The
32 proportion of five dominant species at the section exhibited an evolutionary trend from the
33 “*Bairdia*” group to the “*Liuzhinia antalyaensis-Bairdiacypris ottomanensis*” group.
34 Furthermore, the evolution of the ostracod fauna was divided into six stages according to the
35 changes of dominant species, which indicates that the microbialite environment was not entirely
36 constant but fluctuated during the post-extinction interval.

37 **Keywords:** Ostracod evolution; end-Permian mass extinction; paleoecology; paleoenvironment;
38 Paleo-Tethys.

39

40 **1. Introduction**

41

42 During the end-Permian mass extinction, 80 to 96% of marine species and 70% of
43 continental species were decimated. This massive collapse in species abundance and diversity
44 induced dramatic changes in the structure of ecosystems (Sepkoski, 1984; Valen, 1984; Fischer

45 and Erwin, 1993; Benton, 1995, 2010; Benton and Twitchett, 2003; Alroy et al., 2008). Just
46 after the PTME, microbialite deposits were widespread on shallow-marine platforms all around
47 the margins of the Paleo-Tethys Ocean (Wang et al., 2005; Kershaw et al., 2007, 2012; Chen et
48 al., 2011; Chen and Benton, 2012). In general, these Permian-Triassic Boundary Microbialites
49 (PTBMs) are considered to be abnormal marine environment under low oxygen condition with
50 low biodiversity (Baud et al., 1997, Kershaw et al., 2007, 2012; Crasquin et al., 2010; Chen and
51 Benton, 2012; Chen et al., 2014). However, since twenty years additionally to conodonts,
52 presence of small metazoans, including ostracods, microgastropods and microconchids is
53 evidenced (Kershaw et al., 1999; Ezaki et al., 2003; Crasquin-Soleau and Kershaw, 2005; Wang
54 et al., 2005; Crasquin-Soleau et al., 2006, 2007; Crasquin et al., 2008; Forel et al., 2009, 2011,
55 2015; Forel and Crasquin, 2011; Yang et al., 2011, 2015; Forel, 2012, 2013, 2015; Crasquin and
56 Forel, 2014; Hautmann et al., 2015; Wu et al., 2017; Foster et al., 2018). At the Zuodeng section,
57 Guangxi, South China, a new ostracod fauna was discovered in the PTBMs and the adjacent
58 layers. Detailed analyses of the ostracod fauna, including taxonomy and paleoecology, provide
59 better understanding of the PTBM environment.

60

61 **2. Geological setting**

62

63 The Zuodeng section (23°27.112' N, 106°59.846' E) is located in Tiandong County, Baise
64 City, Guangxi Zhuang Autonomous Region, South China. During the Permian-Triassic (P-Tr)
65 transition, this area belonged to the southern part of the Yangtze block and was part of an
66 isolated carbonated platform surrounded by a deep-water basin (Fig. 1). This section outcrops

67 the Upper Permian Heshan Formation and the Lower Triassic Luolou Formation (Fig. 2). The
68 Heshan Formation is dominated by micritic limestone, with a characteristic thick, light-gray,
69 bioclastic bed (2.9 m) at the top. The contact between the lower part of the Luolou Formation
70 and underlying Permian bioclastic limestone of the Heshan Formation is an irregular surface.
71 The Luolou Formation is made of thrombolite beds intercalated with micritic limestone (Fig.
72 2A-B). In previous studies, these thrombolites were regarded as a whole unit (Luo et al., 2011a,
73 b, 2014; Fang et al., 2017). Here, we recognize five beds named Mb1 to Mb5 from the bottom
74 to the top. The microbialites begin after the end-Permian mass extinction (EPME) (Yang et
75 al., 2011; Yin et al., 2014; Tian et al., 2019) and end at the top of Mb5, overlaid by a 0.6 m thick
76 yellow mudstone layer (Fig. 2C). The conodont *Hindeodus parvus* was found in the lower part
77 of the Luolou Formation at approximately three meters above the top of the Heshan Formation
78 (Yang et al., 1999; Yan, 2013; Fang et al., 2017). Following Jiang et al. (2014) and Yin et al.
79 (2014), who suggested that the PTBMs should begin in the conodont *Hindeodus parvus* Zone,
80 we placed the P-Tr boundary at the top of the Heshan Formation.. The bioclastic limestone
81 underlying the microbialite interval exhibits high diversity, with abundant foraminifers, as
82 *Nankinella* sp. (Fig. 2E), some ostracods and various fragments of brachiopods, bivalves and
83 algae. (Fig. 2D-E). Both Mb1 and Mb2 correspond to microbial deposits containing few
84 ostracods and foraminifers (Fig. 2F-G). From Mb3 to Mb5, the fauna from the thrombolites is
85 generally poor but ostracods and microconchids are relatively common (Fig. 2H-J). After the
86 microbialite interval, numerous fragments of foraminifers and metazoans including ostracods
87 indicate that diversity increase a little (Fig. 2K). Carbon and nitrogen isotopic analysis display
88 important negative shifts immediately after the EPME and low values during the entire

89 microbialite interval (Luo et al., 2011a, b, 2014). This confirm a toxic environment for most of
90 organisms. Increase of temperatures due to episodic volcanic activities is evoked, among
91 adverse effects (Tong et al., 2007; Luo et al., 2011a, b, 2014; Sun et al., 2012).

92

93 **3. Materials and methods**

94

95 Forty-eight samples labeled Zd-xx were collected from the microbialites and their adjacent
96 beds at the Zuodeng section and processed using “hot acetolysis” (Lethiers and Crasquin-
97 Soleau, 1988; Crasquin-Soleau et al., 2005). This method allows to release carbonated ostracod
98 shells from hard limestones, Completely dry samples were reduced to small pieces and covered
99 with pure acetic acid and placed on a heated sand-bath at a temperature of 70–80°C. After a
100 couple of days to two or three weeks of reaction, and when sufficient muddy deposits were
101 present, the samples were washed with running water through sieves and dried again., 1070
102 ostracod specimens were picked. Typical specimens were chosen to be photographed under a
103 scanning-electron microscope (SEM) for identification (Figs. 3 and 4).

104

105 **4. Results**

106

107 *4.1 Composition of ostracod fauna*

108

109 Fifty-three species belonging to fourteen genera were identified. We follow the systematic
110 classifications of Moore (1961) and Becker (2002). Fig. 5 shows the distribution of ostracods

111 at the Zuodeng section. The systematic is reported in the Supplementary Information. The
112 specimens are housed in the collections of China University of Geosciences -Wuhan with
113 numbers ZD-x, 00x_15ZD_xxx) and of Sorbonne University – Paris (with numbers P6Mxxx)
114 Most of the specimens have smooth shells and belong to Palaeocopida (1 species), Platycopida
115 (1 species), Metacopina (8 species assigned to 4 genera, 15% of the total species) and
116 Podocopida (43 species belonging to 8 genera, 81% of the total species). Overall, there are 9
117 families, with Bairdiidae dominating in nearly all of the samples. The main break in ostracod
118 history occurs at the P-Tr boundary, and their class can be divided into two large sets: ostracods
119 with Paleozoic affinities (PA) and ostracods with Meso-Cenozoic affinities (MCA) (Crasquin
120 and Forel, 2014). At the generic level, the PA genera include among others, *Acratia*,
121 *Bairdiacypris*, *Cavellina*, *Fabalicypis*, *Hungarella*, *Reviya*, *Kloedenella*, *Microcheilinella* and
122 *Volganella*. 75% of these genera cross the P-Tr boundary and represent 58.3% of the Lower
123 Triassic genera. The MCA genera are represented here by *Liuzhinia* and *Paracypris* and are
124 already present in the Upper Permian with 16.7% of all genera (Fig. 6C). At the specific level,
125 53 species are found in total, with five dominant species named the “*Strong Five*”: *Liuzhinia*
126 *antalyaensis* Crasquin-Soleau, 2004; *Bairdia davehornei* Forel, 2013; *Bairdia? kemerensis*
127 Crasquin-Soleau, 2004; *Bairdia wailiensis* Crasquin-Soleau, 2006 and *Bairdiacypris*
128 *ottomanensis* Crasquin-Soleau, 2004 (Fig. 5, the names of the “*Strong Five*” are in bold). These
129 species are recognized in the majority of the productive samples, and their proportional
130 abundance could reached 50% in some of the samples (Fig. 7A-B).

131

132 *4.2 Variations of ostracod distribution*

133

134 At the Zuodeng section, ostracods were collected from the upper part of the Heshan
135 Formation (Zd-01) up to the lower part of the Luolou Formation (Zd-48), including the totality
136 of Lower Triassic microbialites. Forty-two of the 48 samples within this interval yielded
137 ostracods. With the exception of the barren samples, ostracod abundance varied from 1
138 specimen (Zd-10, Zd-34 and Zd-37) to 129 specimens (Zd-41), and specific richness varied
139 from 1 (Zd-10, Zd-28, Zd-34 and Zd-37) to 27 (Zd-41). The variations in abundance and specific
140 richness vary nearly in parallel with several peaks (P) and drops (D) (Fig. 6A-B). The first peak
141 of specific richness (P1) occurred in sample Zd-09. The first drop (D1) took place in samples
142 Zd-09 and Zd-10, with specific richness decreasing from 16 to 1, thereby keeping low
143 abundance and diversity within Mb1. A relatively high diversity (P2) presented in Mb2, with
144 both the specific richness and abundance increasing from sample Zd-15 to Zd-16. However, a
145 slight reduction of specific richness (D2) followed in sample Zd-17. The abundance and specific
146 richness fluctuated throughout Mb3 (from sample Zd-18 to Zd-22) until reaching the third peak
147 (P3). Thereafter, specific richness reduced (D3) again from sample Zd-23 to Zd-24 and
148 exhibited low-level fluctuations from samples Zd-24 to Zd-30. Just above Mb4, an obvious re-
149 diversification (P4) appeared in sample Zd-31, which was followed by a rapid reduction in the
150 number of species (D4) from samples Zd-32 to Zd-39, where the ostracods nearly disappear. In
151 the upper part of Mb5, diversification (P5) unfold in samples Zd-40 to Zd-41. Finally, the
152 abundance and specific richness reduced after sample Zd-42.

153

154 **5. Discussion**

155

156 *5.1 Evolution of ostracod fauna at the Zuodeng section*

157

158 *5.1.1 Abundance and diversity of ostracods*

159 According to the curves of ostracod biodiversity at the Zuodeng section, all of the increases
160 in ostracods are associated with the microbialites except for P1, which is located below the
161 microbialite interval. P2, P3 and P5 appear in the upper parts of Mb2, Mb3 and Mb5,
162 respectively. Nevertheless, Mb4 is very thin and ostracod responsiveness may have been
163 delayed such that P4 is not within but following the microbialites. All of the ostracod
164 biodiversity peaks take place after each occurrence of the microbialites, thus supporting the
165 idea of a two-step oxygenation mechanism in the microbialites as mentioned in Forel (2013).
166 Furthermore, there is an upward diversification trend in Mb1, although it is not obvious due to
167 the mass extinction event. In fact, the ostracods exhibit a general reduction of ***, nearly to the
168 point of disappearance, in the parts without the microbialites. Therefore, the four peaks and
169 drops of ostracod abundance and specific richness variations are evident just following the
170 setting and demise of the microbialites respectively. The barren biological features of this
171 section and its abnormal geochemistry signals confirm, once again, the deleterious environment
172 in which the microbialites were deposited. However, the absence of ostracod predators coupled
173 with a sufficient food supply and the possibility of localized and relatively better-oxygenated
174 conditions provided by the boom of cyanobacteria may have enabled ostracods as opportunists
175 to inhabit limited hospitable niches within the microbialite ecosystem (Forel et al., 2009, 2013;
176 Forel, 2012, 2013).

177

178 *5.1.2 Proportion of Paleozoic and Meso-Cenozoic affinities*

179 Below the microbialite intervals, the PA genera, including *Acratia* and *Bairdiacypris*,
180 dominated ostracod assemblages. However, it is worth noting that some genera belonging to
181 the MCA acted as pioneers and were already present at the Zuodeng section (Fig. 6C) as they
182 were at other sections (Crasquin and Forel, 2014). In the lower part of Mb1, the diversity of
183 ostracods is extremely low as observed for other metazoans due to the mass extinction.
184 Meanwhile, the MCA forms became the dominant members in the ostracod fauna. Until Mb2,
185 the diversity of ostracods recovered with increase of PA genera. In Mb3, both diversity and
186 proportion of PA genera are relatively low in the lower layers and increase in the upper layers.
187 Regarding Mb4, the thinnest microbialite part suggests that the microbial boom may have
188 reduced for a short time. The ostracods are rare with only MCA forms, very similar to Mb1
189 forms. Interestingly, however, a brief rise in diversity and increased PA forms appear in the
190 underlying micritic limestone following the microbialite deposit. Finally, the trend in the
191 proportional variation of PA and MCA genera in Mb5 is the same as in Mb3.

192 Above all, the proportional changes in PA genera are approximately synchronous with the
193 biodiversity curves. In other words, the increase in PA forms follows the occurrence of
194 microbialites (Fig. 6C). There is a slight reduction in the proportion of all the PA forms,
195 although most of them survived throughout the mass extinction. Two genera belonging to the
196 MCA emerged before the P-Tr boundary and are distributed across the microbialite interval.
197 Therefore, at the Zuodeng section, Paleozoic survivors crossed the P-Tr Boundary and Meso-
198 Cenozoic affinities didn't have obvious bloom. This might indicate that the survival interval of

199 the ostracods lasted for a long period of time and occurred before the recovery from the EPME,
200 as observed in other neritic environments with microbialites (Crasquin and Forel, 2014).

201

202 *5.2 Comparison with ostracods from other microbialites deposits*

203

204 In comparison with ostracod fauna from other contemporary microbialite sections, the
205 available materials in the eastern Paleo-Tethys Ocean mainly come from South China, i.e., the
206 Laolongdong (Chongqing, Crasquin-Soleau and Kershaw, 2005), Jinya (Guangxi, Crasquin-
207 Soleau et al., 2006), Chongyang (Hubei, Liu et al., 2010) and Dajiang (Guizhou, Forel, 2012)
208 sections. In the western Paleo-Tethys, microbialite-related ostracods have been reported from
209 the Bulla (Italy, Crasquin et al., 2008), Bálvány (Hungary, Forel et al., 2013), Cürük (Turkey,
210 Forel, 2015) and the Elikah (Iran, Forel et al., 2015) sections. The Family Bairdiidae dominates
211 at all of the above sections. The proportion of the MCA forms (16.7%) in the Upper Permian
212 from the Zuodeng section is similar to the Elikah section (12%) but lower than that at the
213 Bálvány (18%), Chongyang (22%), Bulla (23%), Cürük (31%) and Dajiang (44%) sections.
214 The proportion of PA forms during the Griesbachian is approximately 50% at almost all of the
215 sections mentioned above. Several widespread species have been found within the PTBMs
216 (Table. 1), although the rest of the compositions at the specific level are different from one to
217 another. The migration of benthic ostracods is passively driven by bottom ocean currents
218 (Lethiers and Crasquin-Soleau, 1995; Forel, 2012). The similarities and differences between
219 ostracod faunas from different localities indicate endemic features at the specific level and the
220 partial connection of marine environments of the Paleo-Tethys margins after the end-Permian

221 mass extinction.

222

223 *5.3 Paleoenvironmental reconstruction*

224

225 *5.3.1 Indicators of paleoecology and oxygenation*

226 Ostracod assemblages are traditionally considered an important guide for the analysis of
227 paleoenvironments. For example, Bairdioidea members are widely found in shallow to deep,
228 open carbonate environments with normal salinity and oxygen levels, although this assertion is
229 currently challenged due to the outstanding adaptive potential of this superfamily (Forel, 2015).
230 In contrast, Kloedenelloidea members are common in very shallow euryhaline environments
231 (Melnyk and Maddock, 1988). Based on previous studies investigating the relationship between
232 paleoenvironments and Paleozoic ostracod (Melnyk and Maddocks, 1988; Crasquin-Soleau and
233 Kershaw, 2005; Crasquin-Soleau et al., 2006; Brandão and Horne, 2009; Forel, 2012), we
234 divided our ostracods assemblages into three paleoecological groups: Group 1: Kloedenelloidea,
235 Kirkbyoidea; Group 2: Cavellinidae; and Group 3: Acratiidae, Bairdiidae. From Group 1 to
236 Group 3, the paleoecological groups indicate an increase of water depth and of environment
237 stability. In all of the samples at the Zuodeng section, more than half of the species belonged to
238 Group 3 (mainly Bairdiidae) (Fig. 6D). However, ostracods belonging to Groups 1 and 2 were
239 present, albeit briefly and in a small quantity, at the beginning and end of the microbialites (Fig.
240 6D), which not only confirms that the sea level frequently fluctuated during the P-Tr transition
241 in South China (Jiang et al., 2014; Yin et al., 2014; Fang et al., 2017) but also that the growth
242 and decline of microbialites were closely related to sea-level changes (Kershaw et al., 2007,

243 2012; Fang et al., 2017; Kershaw, 2017).

244 Oceanic anoxic events are considered one of the main factors in the EPME (Erwin, 1994,
245 1997; Benton and Twitchett, 2003; Bond and Wignall, 2010; Winguth and Winguth, 2015),
246 and ostracods are typically used to indicate the oxygenation state of water based on the
247 ecological groups of (super) families and orders (Horne et al., 2011; Forel, 2012, 2015). At the
248 Zuodeng section, Bairdiodea members always dominated the assemblages, which may
249 indicate an open marine environment with normal oxygen conditions. Yang et al. (2015)
250 proposed the existence of “some local oxygenic oases within the microbialite ecosystem in
251 which anoxic water mass prevailed” (page 162 in Yang et al. 2015) based on the uneven
252 occurrence of microconchids with other metazoans in microbialites. Although the results of an
253 analysis of pyrite framboids indicate a dysoxic condition, most of the framboids are so large
254 that they might not be completely syngenetic (Fang et al., 2017). Therefore, the indication of
255 oxygenation based on framboids at the Zuodeng section is still open to debate. Furthermore, a
256 hypothesis proposed by Kershaw (2015) suggesting that pyrite framboids may be carried
257 upward to the oxygenated environment in which microbialites are deposited has not been
258 verified. Regardless, the existence of Bairdiodea and its uneven distribution with other
259 metazoans indicate that, at the least, anoxic/dysoxic water was not completely spread across
260 the ocean during that time. Microbialites provided a specialised environment that may have
261 acted as refuge for ostracods in the immediate aftermath of the End-Permian extinction (Forel
262 2013; Forel et al. 2013).

263 5.3.2 *High-resolution paleoenvironmental variation*

264 Microbialites during the P-Tr interval in the Paleo-Tethys have been recognized as having

265 different structures, such as layered (stromatolites), clotted (thrombolites), branching
266 (dendrolites), and bowl-like structures, and were even structureless (Kershaw et al., 2012; Yang
267 et al., 2019). Forel (2014) discussed the correspondence between the different sedimentological
268 and ostracod faunal units by superfamily compositions. At the Zuodeng section, all of the
269 PTBMs were thrombolites. However, six intervals can be recognized through the proportional
270 changes of ??? and let us to define the “*Strong Five*” from the Upper Permian to the Lower
271 Triassic (Fig. 7A-B).

272 In the samples from the Upper Permian micritic limestone (samples Zd-01 to Zd-06),
273 *Bairdia* specimens dominated, with the common species *Bairdia kemerensis* and *Bairdia*.
274 *davehornei* (Fig. 7B-1, *B. keme.-B. dave.*). In the bioclastic limestone underlying the
275 microbialites (samples Zd-07 to Zd-10), *Bairdia wailiensis* has an advantage in abundance and
276 replaces the previous ones close to the EPME and P-Tr boundary (Fig. 7B-2, *B. waili.*). In later
277 samples, i.e., Zd-11 to Zd-15, *Liuzhinia antalyaensis* joins the “*B. wailiensis* dominated” group
278 and develops throughout the PTBMs (Fig. 7B-3, *L. anta.-B. waili.*). Up until Mb2 (samples ZD-
279 16 to Zd-18), *B. kemerensis* recovers and takes second place in the ostracod fauna, but *L.*
280 *antalyaensis* is still the most common (Fig. 7B-4, *L. anta.*). From Mb2 to Mb4 (samples Zd-18
281 to Zd-30), there is a stage called the “*Strong Five Union*”, which means that five common
282 species came to gradually dominate the fauna together and might suggests that the post-
283 extinction environment tended to be stable and propitious to the ostracods (Fig. 7B-5, *Strong*
284 *Five Union*). However, there are some paleoenvironmental alterations before the last part of
285 microbialites (Mb5). The main compositions of ostracods from samples Zd-31 to Zd-42 change
286 to *L. antalyaensis* and *Bairdiacypris ottomanensis* (Fig. 7B-6, *L. anta.-BC. otto.*), which are

287 regarded as the representative species in other contemporaneous microbialites (Crasquin-
288 Soleau et al., 2004, 2005, 2006; Forel et al., 2013, 2015).

289 The general transition analyzed by identifying common species layer-by-layer throughout
290 the Zuodeng section ranged from the “*Bairdia*” group to the “*L. antalyaensis-BC. ottomanensis*”
291 group, which presents a clear indication of the evolution of Bairdiidae ostracods, which were
292 widely dispersed throughout the P-Tr interval. Moreover, the changes in ostracod faunal
293 composition are related not only to the sedimentological structure but also to more detailed
294 changes that occurred during the deposition of microbialites, even within the same structure. In
295 other words, the microbialite sedimentary environment was not entirely constant but fluctuated
296 during the post-extinction period.

297

298 **6. Conclusions**

299

300 The analysis of Zuodeng ostracods in the microbialites and neighboring beds of the P-Tr
301 boundary shows that microbes may have supported an “ostracod-friendly” although restricted
302 environment after the mass extinction that provided enough oxygen, sufficient food and a
303 scarcity of competitors and predators (Forel et al., 2013, 2017). Furthermore, the ostracod
304 paleoecological groups indicate that the sea level fluctuated frequently during the P-Tr
305 transition at the Zuodeng section and that the growth and subsequent demise of microbialites
306 were closely related to the sea-level changes. Ostracods with Paleozoic affinities spanning
307 across the P-Tr boundary and the ostracod with Meso-Cenozoic affinities didn’t have obvious
308 development.). These results are consistent with the view of Crasquin and Forel (2014), who

309 suggested that the transformation of ostracod faunas during the PTBMs was a survival process
310 rather than a sharp recovery. Indeed the maximum of poverty for the ostracod fauna occurred
311 above this microbial event (Crasquin and Forel, 2014).

312 Compared with ostracod assemblages from other sections around the Paleo-Tethys, the
313 Zuodeng fauna has similar proportions of Paleozoic and Meso-Cenozoic affinities with a
314 Bairdiidae-dominated character. The assemblages differ at the specific level, with few species
315 in common which involve an endemism witness of relative isolation.

316 This work presents the first evidence of variations in ostracod compositions at microbialite
317 sections based on the dominant “*Strong Five*” species. The general transition of the five
318 dominant species along the Zuodeng section is recognized from the “*Bairdia*” group to the “*L.*
319 *antalyaensis*-*B. C. ottomanensis*” group, which shows a clear evolution of Bairdiidae ostracods
320 that were widely spread throughout the P-Tr interval. These high-precision changes indicate the
321 microbialite environment was not constant but fluctuated frequently after the end-Permian
322 extinction, even during the deposition of microbialites with the same sedimentary structure.

323

324 **Acknowledgments**

325

326 We express our appreciation to the editors and reviewers (Prof. David J. Horne, Queen
327 Mary University of London, UK and Prof. Steve Kershaw, Brunel University London, UK) for
328 their constructive suggestions and detailed comments on this manuscript. We are grateful to Mr.
329 Yan Chen, Mr. Taishan Yang, Ms. Qian Ye and Mr. Min Lu (CUG) for their help with the
330 fieldwork and sampling process; to Dr. Marie-Béatrice Forel for her suggestions regarding

331 ostracod taxonomy; and to Prof. Qinglai Feng and Prof. Yongbiao Wang for their guidance and
332 editorial revisions. This work was supported by the National Natural Science Foundation of
333 China (No. 41730320, 41430101, 41572001, 40902002).

334

335

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533

534

Figure captions

535 **Figure 1** Changhsingian paleogeographic map of South China at the *Clarkina meishanensis*
536 Zone (modified from Feng and Algeo, 2014; Yin et al., 2014; Chen et al., 2019). NMBY: North
537 marginal basin of Yangtze Platform; HGG Basin: Hunan-Guizhou-Guangxi basin; and ZFG
538 Clastic Region: Zhejiang-Fujian-Guangdong Clastic Region).

539

540 **Figure 2** Lithological column and field/thin section photographs of the Zuodeng section. A)
541 Field photograph of Upper Permian bioclastic limestone overlain by thrombolites. These two
542 units are separated by an irregular contact surface. The mark pen is 14 cm long. B) Field
543 photograph of the thrombolites in Mb4. The bag is 15 cm x 20 cm. C) Field photograph showing
544 yellow mudstone marking the end of the PTBMs. The mark pen is 14 cm long. D-K) Thin
545 sections photographs of the PTBMs and neighboring beds at the Zuodeng section. D: Bioclastic
546 limestone from Zd-11. E: Foraminifers *Nankinella* sp. from bioclastic limestone of Zd-07. F:
547 Thrombolites from Zd-13 in Mb1. G: Thrombolites from Zd-16 in Mb2. H: Thrombolites from
548 Zd-18 in Mb3. I: Thrombolites from Zd-28 in Mb4. J: Thrombolites from Zd-38 in Mb5. K:
549 Micritic limestone from Zd-45. (Column modified after Yan, 2013; EPME: end-Permian mass
550 extinction; Mb1 to Mb5: five segments of the microbialites; a: algae; bl: bioclastic limestone;
551 Bi: bivalves; Br: brachiopods; f: foraminifers; g: gastropods; m: mudstone; Mc: microconchids;
552 O: ostracods; t: thrombolite; yellow arrow: microbial object; and red dashed line: irregular
553 contact surface).

554

555 **Figure 3** Ostracods from the Zuodeng section (I). 1, *Reviya* sp.: right lateral view of complete

556 carapace, collection number: ZD-11; 2, *Kloedenella?* sp.: left lateral view of complete carapace,
557 collection number: ZD-13; 3, *Acratia* sp.: right lateral view of complete carapace, collection
558 number: 001_15ZD_051; 4, *Acratia* cf. *zhongyingensis* Wang, 1978: right lateral view of
559 complete carapace, collection number: ZD-47; 5, *Bairdiacypris anisica* Kozur 1971: right
560 lateral view of complete carapace, collection number: 002_15ZD_001; 6, *Bairdia* cf. *atudoreii*
561 Crasquin-Soleau, 1996: right lateral view of complete carapace, collection number: P6M3807;
562 7, *Bairdia* cf. *balatonica* Mehes, 1911: right lateral view of complete carapace, collection
563 number: P6M3808; 8, *Bairdia beedei* Ulrich and Bassler, 1906: right lateral view of complete
564 carapace, collection number: P6M3809; 9, *Bairdia davehornei* Forel, 2013: right lateral view
565 of complete carapace, collection number: 009_15ZD_024; 10, *Bairdia fangnianqiao* Crasquin,
566 2010: right lateral view of complete carapace, collection number: 001_15ZD_047; 11, *Bairdia*
567 *fengshanensis* Crasquin-Soleau, 2006: right lateral view of complete carapace, collection
568 number: ZD-257; 12, *Bairdia jeromei* Forel, 2012: right lateral view of complete carapace,
569 collection number: 002_15ZD_009; 13, *Bairdia?* *kemerensis* Crasquin-Soleau, 2004: right
570 lateral view of complete carapace, collection number: P6M3810; 14, *Bairdia* cf. *permagna* Geis,
571 1936: right lateral view of complete carapace, collection number: ZD-195; 15, *Bairdia* cf.
572 *urodeloformis* Chen, 1987: right lateral view of complete carapace, collection number:
573 001_15ZD_004; 16, *Bairdia wailiensis* Crasquin-Soleau, 2006: right lateral view of complete
574 carapace, collection number: P6M3811; 17, *Bairdia* cf. *wailiensis* Crasquin-Soleau, 2006: right
575 lateral view of complete carapace, collection number: ZD-227; 18, *Bairdia* cf. *szaszi* Crasquin-
576 Soleau and Gradinaru, 1996: right lateral view of complete carapace, collection number:
577 P6M3812; 19, *Bairdia* sp. 5 *sensu* Forel, 2012: right lateral view of complete carapace,

578 collection number: P6M3813; 20, *Bairdia* sp. 1: right lateral view of complete carapace,
579 collection number: ZD-223; 21, *Bairdia* sp. 2: right lateral view of complete carapace,
580 collection number: ZD-141; 22, *Bairdia* sp. 3: right lateral view of complete carapace,
581 collection number: ZD-86; 23, *Bairdia* sp. 4: right lateral view of complete carapace, collection
582 number: P6M3814; 24, *Cryptobairdia* sp. : right lateral view of complete carapace, collection
583 number: P6M3815; 25, *Bairdiacypris? caeca* Shi, 1987: right lateral view of complete carapace,
584 collection number: 001_15ZD_035; 26, *Bairdiacypris changxingensis* Shi, 1987: right lateral
585 view of complete carapace, collection number: 002_15ZD_005; 27, *Bairdiacypris fornicatus*
586 Shi, 1982: right lateral view of complete carapace, collection number: 002_15ZD_003. Scale
587 bar: 100 μ m.

588

589 **Figure 4** Ostracods from the Zuodeng section (II). 1, *Bairdiacypris longirobusta* Chen, 1958:
590 right lateral view of complete carapace, collection number: 001_15ZD_033; 2, *Bairdiacypris*
591 *ottomanensis* Crasquin-Soleau, 2004: right lateral view of complete carapace, collection
592 number: P6M3816; 3, *Bairdiacypris zaliensis* Mette, 2010: right lateral view of complete
593 carapace, collection number: 002_15ZD_007; 4, *Bairdiacypris* sp. 1: right lateral view of
594 complete carapace, collection number: P6M3817; 5, *Bairdiacypris?* sp. : right lateral view of
595 complete carapace, collection number: P6M3818; 6, *Fabalitypris parva* Wang, 1978: right
596 lateral view of complete carapace, collection number: P6M3819; 7, *Fabalitypris?* sp. : right
597 lateral view of complete carapace, collection number: P6M3920; 8, *Liuzhinia antalyaensis*
598 Crasquin-Soleau, 2004: right lateral view of complete carapace, collection number: P6M3821;
599 9, *Liuzhinia guangxiensis* Crasquin-Soleau, 2006: right lateral view of complete carapace,

600 collection number: ZD-39; 10, *Liuzhinia* cf. *venninae* Forel, 2013: right lateral view of complete
601 carapace, collection number: P6M3822; 11, *Liuzhinia* sp. 1: right lateral view of complete
602 carapace, collection number: P6M3823; 12, *Liuzhinia* sp. 2: right lateral view of complete
603 carapace, collection number: P6M3824; 13, *Liuzhinia* sp. 3: right lateral view of complete
604 carapace, collection number: P6M3825; 14, *Silenites* sp. 1: right lateral view of complete
605 carapace, collection number: P6M3826; 15, *Silenites* sp. 2: right lateral view of complete
606 carapace, collection number: P6M3927; 16, *Silenites* sp. 3: right lateral view of complete
607 carapace, collection number: P6M3828; 17, *Paracypris gaetanii* Crasquin-Soleau, 2006: right
608 lateral view of complete carapace, collection number: ZD-264; 18, *Paracypris* sp. 1 *sensu* Forel,
609 2014: right lateral view of complete carapace, collection number: P6M3829; 19, *Paracypris*?
610 sp.: right lateral view of complete carapace, collection number: ZD-159; 20, *Microcheilinella*
611 sp. 1: right lateral view of complete carapace, collection number: 001_15ZD_017; 21,
612 *Microcheilinella* sp. 2: right lateral view of complete carapace, collection number: P6M3830;
613 22, *Microcheilinella* sp. 3: right lateral view of complete carapace, collection number:
614 001_15ZD_003; 23, *Hungarella tulongensis* Crasquin, 2011: right lateral view of complete
615 carapace, collection number: P6M3831; 24, *Hungarella* sp. : right lateral view of complete
616 carapace, collection number: P6M3832; 25, *Cavellina* cf. *triassica* Crasquin, 2008: right lateral
617 view of complete carapace, collection number: P6M3833; 26, *Volganella? minuta* Wang, 1978:
618 right lateral view of complete carapace, collection number: P6M3834. Scale bar: 100 μ m.

619

620 **Figure 5** Distribution of ostracods at the Zuodeng section. (Column modified after Yan, 2013;

621 Mb1 to Mb5: five segments of the microbialites; the names of the most frequent species

622 (“*Strong Five*”) are in bold).

623

624 **Figure 6** Evolution of the ostracod faunas throughout the P-Tr Boundary at the Zuodeng section

625 (I). A) Variation in species richness. B) Variation in abundance. C) Percent variation of the PA

626 and MCA forms. D) Proportional change in paleoecological groups. (Column modified after

627 Yan, 2013; EPME: end-Permian mass extinction; Mb1 to Mb5: five segments of the

628 microbialites; PA: Paleozoic affinities; MCA: Meso-Cenozoic affinities; Group 1:

629 Kloedenelloidea, Kirkbyoidea; Group 2: Cavellinidae; Group 3: Acratiidae, Bairdiidae).

630

631 **Figure 7** Evolution of the ostracod faunas throughout the P-Tr Boundary at the Zuodeng section

632 (II). A) Continuous change in faunal composition defined by the “*Strong Five*” and other

633 species. B) Percent circular diagrams of faunal compositions for each interval. (Column

634 modified after Yan, 2013; EPME: end-Permian mass extinction; Mb1 to Mb5: five segments of

635 the microbialites; *B. dave*: *Bairdia davehornei* Forel, 2013; *B. keme.*: *Bairdia? kemerensis*

636 Crasquin-Soleau, 2004; *B. waili.*: *Bairdia wailiensis* Crasquin-Soleau, 2006; *L. anta.*: *Liuzhinia*

637 *antalyaensis* Crasquin-Soleau, 2004; *BC. otto.*: *Bairdiacypris ottomanensis* Crasquin-Soleau,

638 2004).

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Table captions

641 **Table 1** Common species between the Zuodeng ostracod fauna and other PTBM ostracod
642 faunas around the Paleo-Tethys. X, same species; cf., *conformis* species.