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

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Abstract

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

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

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

1. Introduction

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

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

2. Geological setting

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

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

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

3. Materials and methods

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

4. Results

4.1 Composition of ostracod fauna

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

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

4.2 Variations of ostracod distribution

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

5. Discussion

5.1 Evolution of ostracod fauna at the Zuodeng section

5.1.1 Abundance and diversity of ostracods

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

5.1.2 Proportion of Paleozoic and Meso-Cenozoic affinities

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

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

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

5.2 Comparison with ostracods from other microbialites deposits

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

mass extinction.

5.3 Paleoenvironmental reconstruction

5.3.1 Indicators of paleoecology and oxygenation

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

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

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

5.3.2 High-resolution paleoenvironmental variation

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

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

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

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

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

6. Conclusions

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

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

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

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

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Figure captions

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

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

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

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

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

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

collection number: ZD-39; 10, *Liuzhinia* cf. *venninae* Forel, 2013: right lateral view of complete carapace, collection number: P6M3822; 11, *Liuzhinia* sp. 1: right lateral view of complete carapace, collection number: P6M3823; 12, *Liuzhinia* sp. 2: right lateral view of complete carapace, collection number: P6M3824; 13, *Liuzhinia* sp. 3: right lateral view of complete carapace, collection number: P6M3825; 14, *Silenites* sp. 1: right lateral view of complete carapace, collection number: P6M3826; 15, *Silenites* sp. 2: right lateral view of complete carapace, collection number: P6M3927; 16, *Silenites* sp. 3: right lateral view of complete carapace, collection number: P6M3828; 17, *Paracypris gaetanii* Crasquin-Soleau, 2006: right lateral view of complete carapace, collection number: ZD-264; 18, *Paracypris* sp. 1 *sensu* Forel, 2014: right lateral view of complete carapace, collection number: P6M3829; 19, *Paracypris*? sp.: right lateral view of complete carapace, collection number: ZD-159; 20, *Microcheilinella* sp. 1: right lateral view of complete carapace, collection number: 001_15ZD_017; 21, *Microcheilinella* sp. 2: right lateral view of complete carapace, collection number: P6M3830; 22, *Microcheilinella* sp. 3: right lateral view of complete carapace, collection number: 001_15ZD_003; 23, *Hungarella tulongensis* Crasquin, 2011: right lateral view of complete carapace, collection number: P6M3831; 24, *Hungarella* sp. : right lateral view of complete carapace, collection number: P6M3832; 25, *Cavellina* cf. *triassica* Crasquin, 2008: right lateral view of complete carapace, collection number: P6M3833; 26, *Volganella*? *minuta* Wang, 1978: right lateral view of complete carapace, collection number: P6M3834. Scale bar: 100 μm.

Figure 5 Distribution of ostracods at the Zuodeng section. (Column modified after Yan, 2013; Mb1 to Mb5: five segments of the microbialites; the names of the most frequent species

("*Strong Five*") are in bold).

Figure 6 Evolution of the ostracod faunas throughout the P-Tr Boundary at the Zuodeng section (I). A) Variation in species richness. B) Variation in abundance. C) Percent variation of the PA and MCA forms. D) Proportional change in paleoecological groups. (Column modified after Yan, 2013; EPME: end-Permian mass extinction; Mb1 to Mb5: five segments of the microbialites; PA: Paleozoic affinities; MCA: Meso-Cenozoic affinities; Group 1: Kloedenelloidea, Kirkbyoidea; Group 2: Cavellinidae; Group 3: Acratiidae, Bairdiidae).

Figure 7 Evolution of the ostracod faunas throughout the P-Tr Boundary at the Zuodeng section (II). A) Continuous change in faunal composition defined by the "*Strong Five*" and other species. B) Percent circular diagrams of faunal compositions for each interval. (Column modified after Yan, 2013; EPME: end-Permian mass extinction; Mb1 to Mb5: five segments of the microbialites; *B. dave*: *Bairdia davehornei* Forel, 2013; *B. keme.*: *Bairdia*? *kemerensis* Crasquin-Soleau, 2004; *B. waili.*: *Bairdia wailiensis* Crasquin-Soleau, 2006; *L. anta.*: *Liuzhinia antalyaensis* Crasquin-Soleau, 2004; *BC. otto.*: *Bairdiacypris ottomanensis* Crasquin-Soleau, 2004).

Table captions

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