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Diverse earliest Triassic ostracod fauna from the non-microbialite-bearing shallow marine carbonates of the Yangou section in South China

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Since diverse ostracod faunas in the immediate aftermath of the latest Permian mass extinction were mainly found within Permian-Triassic boundary microbialites (PTBMs), the idea of an ostracod “microbial related refuge” has been proposed. Here we report a diversified earliest Triassic ostracod fauna from the Yangou section in South China, where no PTBMs were deposited, providing evidence inconsistent with the “microbial related refuge” hypothesis. Meanwhile, a significant ostracod extinction was recorded, corresponding with the earliest Triassic mass extinction (ETME). This ETME of ostracods was associated with size increases and a length/height ratio (L/H) decrease, indicating varied evolutionary patterns of shape and size of ostracods through the Permian-Triassic (P-Tr) extinction events. Although the nature of these biotic changes is somewhat unclear, the temporally varied “refuge zone” scenario provides us a window to reconstruct the environmental dynamics of ecosystem changes during the P-Tr transition.

Key words: *Hollinella*, body size, mass extinction, refuge zone, recovery, marine ecosystem

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Earliest Triassic ostracod fauna of Yangou

As one of the major components of the marine benthic ecosystem, ostracods were heavily affected by the Permian-Triassic (P-Tr) crisis, in which over 90% of marine invertebrate species and 70% of terrestrial animals went extinct (e.g. [Erwin 1994](#); [Benton & Twitchett 2003](#); [Shen *et al.* 2011](#); [Payne & Clapham 2012](#); [Benton & Newell 2014](#)). The extinction rates of the latest Permian ostracod faunas exceeded 70% and may be 100% in some localities ([Crasquin & Forel 2014](#)) during the major phase of the P-Tr crisis, corresponding to the latest Permian mass extinction (LPME) of [Song *et al.* \(2013\)](#).

Many researchers have attempted to explore survival and recovery patterns by studying well-preserved fossil faunas of the extinction aftermath in the Early Triassic (e.g. [Twitchett *et al.* 2004](#); [Benton *et al.* 2004, 2013](#); [Song *et al.* 2011](#); [Brayard *et al.* 2010, 2017](#); [Hautmann *et al.* 2015](#); [Godbold *et al.* 2017](#); [Ji *et al.* 2017](#); [Zhang *et al.* 2017](#)). Ostracods have also attracted great research interest because of their wide habitat ranges and ecological significance (e.g. [Wang 1978](#); [Kozur 1991](#); [Crasquin *et al.* 2007a, b](#); [Yuan 2008](#); [Crasquin & Forel 2014](#); [Chu *et al.* 2015](#); [Forel *et al.* 2015a](#)). Dozens of publications have reported P-Tr ostracod faunas in various facies, including neritic clastic ([Hao 1992](#)), shallow carbonate (e.g. [Crasquin *et al.* 2005, 2006, 2007b, 2018](#); [Forel *et al.* 2009, 2013a, 2013b, 2015a, 2015b](#)), and slope and deeper facies ([Yuan *et al.* 2007](#); [Crasquin *et al.* 2010](#)).

The exceptionally high abundance and diversity of ostracods in Permian-Triassic boundary microbialites (PTBM) was thought to be evidence for a “microbial related refuge” scenario in the immediate aftermath of the LPME ([Forel *et al.* 2009, 2012, 2013](#)). However, herein we present a newly discovered diversified ostracod fauna in the earliest Triassic non-microbialite, shallow marine carbonates of the Yangou section, as a means of testing the “microbial related refuge” scenario. Meanwhile, temporal diversity and abundance changes as well as size variations are analyzed to

explore the impact on shallow marine ostracods of the second phase of the P-Tr crisis, the earliest Triassic mass extinction (ETME; identified by [Song *et al.* \(2013\)](#)). Furthermore, our quantitative data also show some inconsistent results with the newly established ontogeny model of *Hollinella lungcamensis* ([Crasquin *et al.* 2018](#)), providing additional evidence for systematic re-evaluation of *Hollinella*.

Geological setting and method

The Yangou section was located on the northern margin of the Yangtze Platform during the P-Tr transition ([Fig. 1](#)), in the eastern-most Paleotethys realm ([Fig. 1](#)). The studied P-Tr successions are composed of the Upper Permian Changxing Formation and Lower Triassic Daye Formation, with continuous deposition of carbonates ([Fig. 2](#)). The Changxing Formation is dominated by medium-thick bedded limestones, overlain by the Daye Formation and its thin-medium bedded limestones and muddy limestones. Two oolitic limestone beds were found at the base of the Daye Formation, implying shallow seawater level ([Tian *et al.* 2014a, b](#)). These lithologies and microfacies analyses suggest a platform–margin facies ([Fig. 3; Tian *et al.* 2014a](#)).

The study interval can be well constrained by other well studied P-Tr sections in South China, both lithologically and bio-stratigraphically ([Song *et al.* 2012; Sun *et al.* 2012; Tian *et al.* 2014a, 2015](#)), providing a solid stratigraphic basis for further palaeontological study and correlations. Ostracods and other fossils of the P-Tr successions in the study areas were initially reported by [Zhu \(1999\)](#), but the results were unreliable in the absence of fossil photographs and detailed descriptions. Renewed outcrop exposure for cement quarrying was bio-stratigraphically constrained at decimetre-level resolution ([Fig. 3](#)) using conodonts by [Sun *et al.* \(2012\)](#). Since then, foraminiferal

extinction (Tian *et al.* 2014b), carbon isotope variation (Song *et al.* 2012), facies and microfacies diagnoses (Tian *et al.* 2014a, 2015), elemental compositions (Li *et al.* 2017) and the carbonate diagenesis history (Li & Jones 2017) have been explored in detail in the Yangou study section.

Field sampling and bulk sample dissolution have been conducted for study of the ostracods and conodonts, as introduced in detail by Sun *et al.* (2012). Note that the acetic acid we used was at 10% concentration, and the use of dilute acid has ensured that dozens of exceptionally well-preserved specimens, like *Hollinella* (Fig. 4 A–H), were retained. All specimens are deposited in the collections of the State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan). The collections have been numbered in this way: LY(section name)**(bed number)+**(sampling number)i**(ostracod specimen number). In all specimens we measured the length (L) and height (H) for quantitative size analyses. Size variations are shown in plotted boxes including length, height, Log(length×height). The specimens belonging to *Hollinella* were plotted in a Height/Length diagram.

Results and Discussion

In total, 238 well preserved ostracod specimens were found from nine sampling horizons (Fig. 3). These ostracods are all from the wackestones of the Daye Formation (Fig. 2B–C; diagnosed as restricted inner-shelf shallow marine facies by Tian *et al.* 2014a), that lack microbial related structures in the matrix (Fig. 2B–C). In total, 34 species belonging to eight genera of ostracods have been identified and measured (Figs. 4–5; Table 1).

New materials for Hollinella classification

89

90 The ostracod *Hollinella* is often present in many P-Tr boundary sections globally (Crasquin et al.
91 2018). However, especially for *Hollinella tingi*, a proposed bio-stratigraphical index for the P-Tr
92 boundary (Kozur 1985), the systematic classification is confused (Crasquin et al. 2018).
93 Morphological variations of *Hollinella* specimens are presented here as a means of testing aspects of
94 their systematic classification. From these samples, we identify three morphotypes, termed sp. 1–3
95 here.

96 *Hollinella* sp. 1 is characterized by its smooth, spineless surface, rounded anterior and posterior
97 borders, straight dorsal margin and two distinct nodules, belonging either to *H. tingi* (Patte 1935) or
98 *H. panxiensis* (Wang 1978), according to the descriptions of these two species by Wang (1978). In
99 the review of the history of *H. tingi* by Crasquin et al. (2018), it is very difficult to trace the real *H.*
100 *tingi* from the indefinite descriptions by Patte (1935) and Hou (1954). Crasquin et al. (2018)
101 interpreted all specimens assigned to *H. tingi* to be *H. panxiensis*, since Wang (1978) established *H.*
102 *panxiensis* with clear descriptions and he indicated differences from *H. tingi*. However, a long dorsal
103 spine and an obtuse spine reaching over the dorsal margin were noted for *H. panxiensis* and *H. tingi*,
104 respectively, by Wang (1978). In the absence of such spines in our *Hollinella* sp. 1 (Fig. 4A–D), it
105 cannot be either *H. panxiensis* or *H. tingi*.

106 *Hollinella* sp. 2 is identified on similar morphological features as *H.* sp. 1, but the occurrence of
107 spinous shells (Fig. 4E–H) suggests it may belong to the species *H. lungcamensis* which was
108 established by Crasquin et al. (2018). These authors proposed an ideal ontogenetic model for its
109 growth stage and sexual dimorphism, and if this ontogeny model is correct, the juveniles (spinous)
110 should be smaller than the adults (with velum), but their H/L ratios fail to show a clear boundary

between juveniles and adults (see [Crasquin et al. 2018, fig. 5](#)). Furthermore, our body size measurements show that *H. sp. 2* should be an independent new taxon based on its wide size distributions ([Fig. 6](#); varying from very small to very large) and coexistence of velum and spinous shells ([Fig. 4E–H](#)).

According to the classification in [Crasquin et al. \(2018\)](#), our *Hollinella sp. 3* should be female adults of *H. lungcamensis* because of the occurrence of a velum and a few spines on the lobes (see [Crasquin et al. 2018, fig. 2, fig. 5A–H](#)). Unfortunately, the actual body size measurements of our specimens fail to show that *H. sp. 2* (interpreted as juveniles of *H. lungcamensis* by [Crasquin et al. \(2018\)](#)) are smaller than *H. sp. 3* ([Fig. 6](#)). The length, positions and spaces of these spines on our *H. sp. 3* are significantly lower than in our *H. sp. 2*. Additionally, there is an obtuse “spine” reaching over the dorsal margin in our *H. sp. 3* ([Fig. 4I–L](#)), making our *H. sp. 3* very similar to *H. capacilacuna*. However, the distinct spinous posterior border was not noted in the description of *H. capacilacuna* ([Wang 1978](#)), and a distinct arcuate ridge in the ventral lobe, around the tumours, on most specimens, has also been observed ([Fig. 4A–C](#)), neither of which was noted in the description of *H. capacilacuna* by [Wang \(1978\)](#). Thus, we cannot confidently assign our *H. sp. 3* to either *H. capacilacuna* or a new species.

In addition, the H/L ratios imply a potential ontogenetic link between these “two species”, *H. sp. 1* and *H. sp. 3* ([Fig. 6](#)). This means that our *H. sp. 1* and *H. sp. 3* might be juvenile and adult of a single species, respectively. In the ontogeny model of *H. camoni*, distinct spines occurred on the posterior margin in the adults, while the shell margin of young juveniles looks smooth, with extremely tiny spines ([Bless 1968](#)). Possible tiny spines on the margin can also be observed on some specimens of our *H. sp. 3* ([Fig. 4I–L](#)), supporting our assumed ontogenetic relationships between *H.*

sp. 1 and *H. sp. 3*.

Earliest Triassic ostracod extinction and associated size variations

Although the absence of pre-LPME specimens precludes the correlation of the LPME extinction pattern with other sections, the succession of earliest Triassic specimens shows a distinct extinction at the top of the *H. parvus* Zone (between LY4 with LY5, see Table 1), corresponding to the ETME (Fig. 7). [Song et al. \(2013\)](#) constrained the ETME to the *Isarcicella staeschei* Zone, as the terminal event of the P-Tr crises. Precise conodont biozonations of the Yangou study section show that the ETME occurred at the top of the *H. parvus* Zone, implying a potential earlier ETME at Yangou (Fig. 3; [Sun et al. 2012](#)). However, because no conodont has been obtained from samples between LY4 and LY6 ([Sun et al. 2012](#)), it is likely that the true lowest occurrence of *Isarcicella staeschei* might be lower than LY5, dating the ETME at Yangou to the *Isarcicella staeschei* Zone.

Differing from the observed Lilliput effect of ostracods during the LPME ([Chu et al. 2015](#); [Forel et al. 2015a](#); [Forel & Crasquin 2015](#)), we find that sizes (Length, Height and Length*Height) show a gradual increase across the ETME at Yangou (Fig. 8A). Possible reasons could be either or both: 1) body size had been reduced to a very low level in the LPME by severe environmental devastation, and the following environmental oxygenation contributed to rapid reoccupation and size increase ([He et al. 2017](#)); or 2) Cope's rule (e.g. [Hone & Benton 2005](#); [Benson et al. 2017](#)) applied to the surviving populations (*Hollinella* sp. 1) and new-comers (*Hollinella* sp. 2 and *Hollinella* sp. 3) in the aftermath of the ETME. Although numerous studies just reported size reduction during the P-Tr mass extinction (e.g. ostracods: [Chu et al. 2015](#); [Forel et al. 2015](#); brachiopods: [He et al. 2010, 2015](#); conodonts: [Luo et al. 2008](#); foraminifera: [Song et al. 2011](#); and see [Twitchett, 2007](#)), a body size

increase across the second extinction phase has been noted in brachiopods (Wu *et al.* 2018) and ostracods (this study), and further such high-resolution studies are required to decipher these unique biotic response dynamics in mass extinctions.

Size variations of ostracods might be biased by the dominance of adults/juveniles (Forel *et al.* 2015a), but the results cannot be further tested for the problematic ontogenetic models we noted above. Fossil size changes could indicate ecosystem stress. Payne *et al.* (2004) stated that the recovery in the aftermath of the LPME lasted over 5 Myr, based on the delayed size increase of gastropods in the Middle Triassic. Brayard *et al.* (2010) argued that the rapid size increase of gastropods in the Smithian (about 1 Myr after LPME) indicated rapid ecosystem recovery. However, the transient ostracod size increase we observe in the *Hindeodus parvus* Zone did not result from rapid ecosystem recovery, but the domination by *Hollinella* suggests they were opportunistic assemblages rather than recovered Mesozoic assemblages (Crasquin *et al.* 2007b). Such dynamics have also been applied to explain the synchronous brachiopod size increase in deeper settings by Wu *et al.* (2018). Additionally, temporary environmental improvements during the *H. parvus* Zone (details below) also contributed to this assemblage replacement and the associated size increase.

Chu *et al.* (2015) reported a reduction in L/H ratios for ostracods during the LPME. Forel & Crasquin (2015) argued that the differential extinction of ostracods with high L/H ratios provides a new proxy together with body size (length, height and volume) to explore the nature of extinctions. On the other hand, our results suggest that the L/H ratio decreased during the ETME at Yangou (Fig. 8B; the slight increase in LY7 is meaningless, as it is based on only one measurement). The measured L/H ratio distributions in *Hollinella*, *Bairdia* and *Acratia* show smaller L/H ratios than other genera (Fig. 9). Indeed, the post-ETME assemblages are dominated by *Hollinella* with very

few *Bairdia* (Fig. 7), indicating potentially higher survival probability for the low L/H specimens. However, *Acratia* went extinct during the ETME despite its low L/H, implying additional unclear extinction/survival dynamics.

Reconsideration of the “microbial related refuge” scenario for ostracods during the P-Tr transition

The high diversity and abundance of the ostracod faunas in the *H. parvus* Zone presented here suggest that Yangou is a potential earliest Triassic favourable metazoan habitat (refuge). Such an occurrence of ostracods in Permian-Triassic transitional beds (PTTB) is notable when compared to other settings globally (Table 2). At the P-Tr boundary GSSP Meishan section, although the abundance and diversity in Bed 27 is lower than in the strata below Bed 24e, ostracods did not go totally extinct until Bed 30 (Crasquin *et al.* 2010; Forel *et al.* 2011). In the Dajiang section in South China, ostracods are abundant in shelly layers within PTBMs (Forel *et al.* 2009; Forel 2012), which were most recently constrained to belong to the *H. parvus* Zone (Jiang *et al.* 2014). Similar high diversity and abundance of ostracods within PTBMs have also been reported in the Chongyang and Laolongdong sections on the Yangtze Platform, the Lung Cam section in Vietnam, and the Cürük Dag section in Turkey (Crasquin & Kershaw 2005; Liu *et al.* 2010; Crasquin *et al.* 2018). Including the Yangou section, ostracods are also abundant and diversified in the *H. parvus* Zone in some oolite-bearing P-Tr successions, such as Bulla in Italy and Balvány in Hungary as well as the Elikah River section (Crasquin *et al.* 2004; Forel *et al.* 2013a, 2015b), from the latest Permian to earliest Triassic. Earliest Triassic ostracod faunas have also been found in the *Clarkina meishanensis* Zone–*H. parvus* Zone equivalent strata in siliceous P-Tr successions in Guizhou and Yunnan (Wang 1978; Hao 1992; Yu *et al.* 2010; Chu *et al.* 2016). It is worth noting that all these mentioned sections

were in shallow water facies.

The “microbial related refuge” proposed by [Forel *et al.* \(2009\)](#) is somewhat ambiguous in terms of the complicated ecological interactions between metazoans and microbialites. Thrombolites are characterized by a mixed bacterial-metaphyte ecosystem of greater complexity than the microbial-dominated biotas of stromatolitic mats in the modern Bahamian Platform ([Planavsky & Ginsburg 2009](#); [Tarhan *et al.* 2013](#)). The thrombolites of PTBMs always have a much greater metazoan fossil content (e.g. [Yang *et al.* 2011](#); [Tang *et al.* 2017](#); [Tian *et al.* 2018](#)) than coeval stromatolitic mats, which tend to contain few marine invertebrates (e.g. [Adachi *et al.* 2017](#); [Fang *et al.* 2017](#)). Shelly layers, dominated by ostracods and gastropods, are very common in PTBMs (e.g. [Kershaw *et al.* 2012](#)). However, these shelly layers or shell lenses are often preserved between the PTBMs, hydrodynamically accumulated in troughs between the microbial domes ([Hautmann *et al.* 2015](#)), and showing no evidence that metazoans lived in these microbial domes.

Abundant diversified ostracod faunas of the earliest Triassic might be biotic responses to a sharp break in environmental devastation in the *H. parvus* Zone. The high abundance and diversity of ostracod faunas within PTBMs were interpreted as evidence of habitable conditions, which were provided by PTBMs as potential refuges ([Forel *et al.* 2009, 2013](#)). The abundances of ostracods within PTBMs are higher than in other facies, but the diversities of PTTB of shallow successions are equivalent ([Table 2](#)). Therefore, the synchronous intensive and extensive occurrences of ostracods in non-PTBM successions (e.g. Yangou and Bulla) cannot be explained by the microbialite-refuge scenario. Further, reliable evidence for ostracod-grazing microbes is also absent from PTBMs. A high oxygen level for microbial blooms in PTBMs was inferred ([Forel *et al.* 2009, 2013](#)), despite the evidence for dysoxic (not fully oxygenated) conditions in PTBMs ([Brennecke *et al.* 2011](#); [Liao *et al.*](#)

2017; Xiao *et al.* 2018).

Thus, we prefer to accept the idea of a temporally synchronous “shallow-water refuge” in various facies rather than the microbialite-related “refuge”. Song *et al.* (2014) proposed temporal “refuge zone” variations from the latest Permian to Middle Triassic, showing a clear refuge zone expansion in the *H. parvus* Zone, as the potential dynamic for a diversified fauna (including ostracods) between the LPME and the ETME (Song *et al.* 2013). Recent studies have suggested that there is little evidence for conditions favourable to metazoans in the *H. parvus* Zone, such as an oxygenation event (Bond & Wignall 2010; Loopes *et al.* 2013; Li *et al.* 2016; Xiao *et al.* 2018), paused temperature rise (Joachimski *et al.* 2012) or moderate pH (Clarkson *et al.* 2015).

Following the rapidly expanded refuge zone during the time of the *H. parvus* Zone, the ostracod extinction at the ETME was likely caused by synchronous lethal environmental crises, including temperature rise (Joachimski *et al.* 2012), euxinia expanding into the photic zone (Grice *et al.* 2005; Xie *et al.* 2017), ocean acidification (Clarkson *et al.* 2015), carbonate factory overturns (Tian *et al.* 2015) and others. Though the ecological dynamics for survival selectivity of species with low L/H ratios and non-Lilliput effects among ostracods through the ETME uncovered at Yangou are unclear, further eco-physiological research is needed to decipher these unique biotic responses to environmental devastation.

Conclusions

Following the results and discussion presented above, four important conclusions are:

- 1) The new materials of the ostracod genus *Hollinella* show that the current identification and nomenclature of some species is unclear;

- 2) A distinct ostracod extinction horizon is recorded in the earliest Triassic (latest *Hindeodus parvus* Zone or earliest *Isarcicella staeschei* Zone), associated with increasing body size and reducing L/H ratio;
- 3) The diverse ostracod fauna in the Yangou section suggests that ostracods occurred in various carbonate facies, not only PTBMs, during the pause between the LPME and ETME, implying a temporal “refuge zone” in shallow marine settings, rather than the scenario of spatial refuge related to PTBMs;
- 4) Both the diverse ostracod fauna in the *Hindeodus parvus* Zone and ETME, and related size variations uncovered in this study, correspond to rapid ecological and environmental changes, providing new biotic responses (rapid recovery and increase of size) for future mass extinction studies.

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Figure Captions

Fig. 1. Palaeo-geographic maps of the global plates (A) and South China Block (B) during the Permian-Triassic transition. Map B shows the study section location (star) on the Yangtze Platform: YG = Yangou. The GSSP Meishan section is also marked by MS. The South China Block has rotated nearly 90° clockwise since the Permian-Triassic. Map A is adapted from Ron Blakey (<http://jan.ucc.nau.edu/rcb7/>), while map B is modified after Yin *et al.* (2014).

Fig. 2. A. Field photograph of the study section and ostracod-enriched intervals. B, C. Photographs of thin sections. Os = ostracods.

Fig. 3. Lithological, bio-stratigraphic and chemo-stratigraphic profiles of the study section. Conodont zonations are from Sun *et al.* (2012); Microfacies and carbon isotopes are from Tian *et al.* (2014a), MF-3: Algal and foraminiferal bioclastic sparitic limestone; MF-4: Coated-grain-bearing foraminiferal oolitic sparitic limestone; MF-5: Pyrite-bearing micritic limestone; MF-6: Dark shelly micritic limestone. Presented samples in this study are labelled by the narrows along the profiles.

Fig. 4. Ostracods of the Yangou section, part I. Scale bar width = 100 µm. A–D: *Hollinella* sp. 1, A, LY34+16i122, right lateral view, B, LY35+15i011, left lateral view, C, LY35+30i001, right lateral view, D, LY33+15i023, right lateral view; E–H: *Hollinella* sp. 2, E, LY35+10i011, right lateral view,

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505 F, LY35+10i003, right lateral view, G, LY35+10i002, left lateral view, H, LY35+10i001, left lateral
506 view; I–L: *Hollinella* sp. 3, I, LY36+0i012, right lateral view, J, LY36+0i005, right lateral view, K,
507 LY36+0i013, left lateral view, L, LY36+0i003, left lateral view; M: *Langdaia suboblonga*,
508 LY34+16i103, right lateral view; N–O: *Praezabythocypris ottomanensis*, N, LY34+16i093, right
509 lateral view, O, LY34+28i051, right lateral view; P: *Langdaia* cf. *suboblonga*, LY34+16i052, left
510 lateral view; Q–R: *Langdaia laolongdongensis*, Q, LY34+16i081, left lateral view, R, 34+16i052,
511 right lateral view; S–T: *Langdaia* sp., S, LY34+16i053, right lateral view, T, LY34+28i127, right
512 lateral view; U–V: *Paracypris gaetanii*, U, LY34+28i022, right lateral view, V, LY34+28i003, right
513 lateral view; W–X: *Paracypris* cf. *gaetanii*, W, LY34+28i028, left lateral view, X, 34+28i003, right
514 lateral view.

515

516 **Fig. 5.** Ostracods of the Yangou section, part II. Scale bar width = 100 μ m. A–B: *Praezabythocypris*
517 cf. *ottomanensis*, A, LY34+16i116, right lateral view, B, LY34+16i047, left lateral view; C–D:
518 *Acratia changxingensis*, C, LY34+16i047, right lateral view, D, LY34+16i056, left lateral view; E:
519 *Liuzhinia* sp. 2, LY34+16i021, left lateral view; F: *Bairdia davehornei*, LY33+15i008, left lateral
520 view; G–H: *Bairdia baudini*, G, LY34+16i064, left lateral view, H, 34+16i102, left lateral view; I–J:
521 *Bairdia* sp. 1, I, LY34+28i006, right lateral view, J, LY34+28i030, right lateral view; K: *Bairdia* sp. 2,
522 LY34+50i004, left lateral view; L–M: *Bairdiacypris* sp. 2, L, LY34+28i045, left lateral view, M,
523 LY34+16i086, left lateral view; N–O: *Bairdiacypris* sp. 3, N, LY34+28i020, right lateral view, O,
524 LY34+16i048, left lateral view; P: *Liuzhinia* cf. *antalyaensis*, LY34+28i045, right lateral view; Q–S:
525 *Liuzhinia antalyaensis*, Q, LY34+28i031, right lateral view, R, LY34+28i059, left lateral view, S,
526 LY34+28i058, left lateral view; T: *Liuzhinia* cf. *antalyaensis*, LY34+28i049, left lateral view; U:

527 *Liuzhinia* sp. 1, LY34+28i050, right lateral view; V: *Liuzhinia guangxiensis*, LY33+15i003, left
528 lateral view; W-X: *Bairdiacypris?* sp., W, LY34+16i060, left lateral view, X, LY34+16i037, left
529 lateral view.

530

531 **Fig. 6.** Height/Length diagram of the measured *Hollinella*.

532

533 **Fig. 7.** Faunal compositions of each study sample. Detailed data are in Table 1. Conodont zonations
534 are from [Sun et al. \(2012\)](#).

535

536 **Fig. 8.** Temporal size variations in the study samples. ETME = Earliest Triassic mass extinction.
537 Note, only one specimen is contained in the LY7 sample.

538

539 **Fig. 9.** Length/Height ratio distributions of the identified genera.

540

541

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542

Table 1. Distributions of the identified ostracod taxa.

Taxa/Bed	LY1	LY2	LY3	LY4	LY5	LY6	LY7	LY8	LY9
<i>Acratia changxingensis</i> (Shi, 1987)		5							
<i>Acratia</i> sp.1		2		1					
<i>Acratia</i> sp.2		3		3					
<i>Bairdia subsymmetrica</i> (Shi, 1987)		5	2						
<i>Bairdia</i> cf. <i>subsymmetrica</i>		3	1	1					
<i>Bairdia davehornei</i> Forel et al., 2013	1								
<i>Bairdia</i> sp. 1		1	1	1					
<i>Bairdia</i> sp. 2		3	1						
<i>Bairdia</i> spp.				2				2	
<i>Bairdiacypris anisica</i> Kozur, 1971		5	1	1					
<i>Bairdiacypris combeae</i> Forel & Crasquin-Soleau, 2011		1	2						
<i>Bairdiacypris</i> sp.	2	2	6						
<i>Bairdiacypris</i> ? sp.		3							
<i>Hollinella</i> sp.1	6	4		6		6	1	1	
<i>Hollinella</i> sp. 2					10	3			
<i>Hollinella</i> sp. 3								1	18
<i>Langdaia laolongdongensis</i> Crasquin-Soleau & Kershaw, 2005		12							
<i>Langdaia</i> cf. <i>laolongdongensis</i>		7	3						
<i>Langdaia suboblonga</i> Wang, 1978		6	1						
<i>Langdaia</i> cf. <i>suboblonga</i>		1	2						
<i>Langdaia</i> sp.	1	2							
<i>Liuzhinia antalyaensis</i> Crasquin-Soleau, 2004		8	15						
<i>Liuzhinia</i> cf. <i>antalyaensis</i>		3							
<i>Liuzhinia guangxiensis</i> Crasquin-Soleau, 2006	2	1	1						
<i>Liuzhinia</i> cf. <i>guangxiensis</i>		8	1						
<i>Liuzhinia</i> sp.1		1	2						
<i>Liuzhinia</i> sp.2			2						
<i>Liuzhinia</i> spp.		8	6						
<i>Paracypris gaetanii</i> Crasquin-Soleau, 2006		1	2						
<i>Paracypris</i> cf. <i>gaetanii</i>		2	1						
<i>Paracypris</i> sp.		3							
<i>Praezabythocypris ottomanensis</i> Crasquin-Soleau, 2004	1	3	4						
<i>Praezabythocypris</i> cf. <i>ottomanensis</i>	2	3	2						
<i>Praezabythocypris</i> spp.	1	2	1						

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545 **Table 2. Ostracod faunal compositions of the detailed studied sections in different facies**

Paleo-geographic facies	Section name	Pre-LPME	PTTB	Post-ETME	References
Neritic clastic facies					
	Longchang	26 species of 15 genera	7 species of 4 genera	*	Hao 1992
	Zhongyin	21 species of 15 genera	5 species of 5 genera	*	Hao 1992
Non-microbialite shallow carbonate facies					
	Yangou	*	33 species of 8 genera	3 species of 2 genera	This study
	Bulla	54 species of 26 genera	15 species of 12 genera	*	Crasquin <i>et al.</i> 2008; Farabgoli <i>et al.</i> 2007
Microbialite-bearing shallow carbonate facies					
	Laolongdong	*	14 species of 8 genera	*	Crasquin & Kershaw 2005
	Chongyang	20 species of 5 genera	14 species of 7 genera	*	Liu <i>et al.</i> 2010
	Dajiang	17 species of 16 genera	10 species of 10 genera	*	Forel 2012
	Elikah River	56 species of 33 genera	29 species of 21 genera	*	Forel <i>et al.</i> 2015a
	Bükk Mountains	54 species of 16 genera	36 species of 15 genera	*	Forel <i>et al.</i> 2015b
	Çürük dag	28 species of 17 genera	12 species of 6 genera	*	Crasquin <i>et al.</i> 2004
Slope and deeper facies					
	Meishan	97 species of 25 genera	4 species of 4 genera	3 species of 3 genera	Crasquin <i>et al.</i> 2010
	Dongpan	48 species of 28 genera	8 species of 7 genera	*	Yuan <i>et al.</i> 2007

Footnote: * means no data. PTTB = Permian-Triassic transitional beds

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Fig. 1

Fig. 2

Earliest Triassic ostracod fauna of Yangou

Fig. 3

559 Fig. 4

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563 Fig. 5

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Fig. 6

Fig. 7

Fig. 8

Fig. 9