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Earliest Triassic ostracod fauna of Yangou

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

XINCHENG QIU, LI TIAN, KUI WU, MICHAEL J. BENTON, DONGYING SUN, HAO YANG AND JINNAN TONG

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

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

*Hollinella* sp. 2 is identified on similar morphological features as *H. sp. 1*, but the occurrence of spinous shells (Fig. 4E–H) suggests it may belong to the species *H. lungcamensis* which was established by Crasquin et al. (2018). These authors proposed an ideal ontogenetic model for its growth stage and sexual dimorphism, and if this ontogeny model is correct, the juveniles (spinous) should be smaller than the adults (with velum), but their H/L ratios fail to show a clear boundary.
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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*.
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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
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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 Balvany 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
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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 (Brennecka et al. 2011; Liao et al. 2015).
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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;
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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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References


Chu, D., Yu, J., Tong, J., Benton, M.J., Song, H., Huang, Y. Song, T. & Tian, L. 2016: Biostratigraphic correlation and
Earliest Triassic ostracod fauna of Yangou


Farabegoli, E., Perri, M.C. & Posenato, R. 2007: Environmental and biotic changes across the Permian-Triassic boundary


Earliest Triassic ostracod fauna of Yangou


Li, R., Jones, B. 2017: Diagenetic overprint on negative $\delta^{13}$C excursions across the Permian/Triassic boundary: A case study from Meishan section, China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 468, 18–33.


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Tian, L., Tong, J., Sun, D., Xiong, Y., Wang, C., Song, H., Song, H. & Huang, Y. 2014a: The microfacies and
Earliest Triassic ostracod fauna of Yangou

sedimentary responses to the mass extinction during the Permian–Triassic transition at Yangou Section, Jiangxi Province, South China. *Science China Earth Sciences* 57, 2195–2207.


Wang, S. 1978: Late Permian and Early Triassic Ostracods of Western Guizhou and Northeastern Yunnan. *Acta Palaeontologica Sinica* 17, 47–138. [In Chinese with English abstract.]


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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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F, LY35+10i003, right lateral view, G, LY35+10i002, left lateral view, H, LY35+10i001, left lateral view; I–L: *Hollinella* sp. 3, I, LY36+0i012, right lateral view, J, LY36+0i005, right lateral view, K, LY36+0i013, left lateral view, L, LY36+0i003, left lateral view; M: *Langdaia suboblonga*, LY34+16i103, right lateral view; N–O: *Praezabythocypris ottomanensis*, N, LY34+16i093, right lateral view, O, LY34+28i051, right lateral view; P: *Langdaia cf. suboblonga*, LY34+16i052, left lateral view; Q–R: *Langdaia laolongdongensis*, Q, LY34+16i081, left lateral view, R, 34+16i052, right lateral view; S–T: *Langdaia* sp., S, LY34+16i053, right lateral view, T, LY34+28i127, right lateral view; U–V: *Paracypris gaetanii*, U, LY34+28i022, right lateral view, V, LY34+28i003, right lateral view; W–X: *Paracypris cf. gaetanii*, W, LY34+28i028, left lateral view, X, LY34+28i030, right lateral view.

**Fig. 5.** Ostracods of the Yangou section, part Π. Scale bar width = 100 μm. A–B: *Praezabythocypris cf. ottomanensis*, A, LY34+16i116, right lateral view, B, LY34+16i047, left lateral view; C–D: *Acratia changxingensis*, C, LY34+16i047, right lateral view, D, LY34+16i056, left lateral view; E: *Liuzhinia* sp. 2, LY34+16i021, left lateral view; F: *Bairdia davehornei*, LY33+15i008, left lateral view; G–H: *Bairdia baudini*, G, LY34+16i064, left lateral view, H, 34+16i102, left lateral view; I–J: *Bairdia* sp. 1, I, LY34+28i006, right lateral view, J, LY34+28i030, right lateral view; K: *Bairdia* sp. 2, LY34+50i004, left lateral view; L–M: *Bairdiacypris* sp. 2, L, LY34+28i045, left lateral view, M, LY34+16i086, left lateral view; N–O: *Bairdiacypris* sp. 3, N, LY34+28i020, right lateral view, O, LY34+16i048, left lateral view; P: *Liuzhinia cf. antalyaensis*, LY34+28i045, right lateral view; Q–S: *Liuzhinia antalyaensis*, Q, LY34+28i031, right lateral view, R, LY34+28i059, left lateral view, S, LY34+28i058, left lateral view; T: *Liuzhinia cf. antalyaensis*, LY34+28i049, left lateral view; U:
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*Liuzhinia* sp. 1, LY34+28i050, right lateral view; V: *Liuzhinia guangxiensis*, LY33+15i003, left lateral view; W-X: *Bairdiacypris?* sp., W, LY34+16i060, left lateral view, X, LY34+16i037, left lateral view.

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

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

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

**Fig. 9.** Length/Height ratio distributions of the identified genera.
### Table 1. Distributions of the identified ostracod taxa.

<table>
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<tr>
<th>Taxa/Bed</th>
<th>LY1</th>
<th>LY2</th>
<th>LY3</th>
<th>LY4</th>
<th>LY5</th>
<th>LY6</th>
<th>LY7</th>
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**Table 2. Ostracod faunal compositions of the detailed studied sections in different facies**

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<th>Paleo-geographic facies</th>
<th>Section name</th>
<th>Pre-LPME</th>
<th>PTTB</th>
<th>Post-ETME</th>
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<td>Neritic clastic facies</td>
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<td>26 species of 15 genera</td>
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<td>21 species of 15 genera</td>
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<td>Non-microbialite shallow carbonate facies</td>
<td>Yangou</td>
<td>*</td>
<td>33 species of 8 genera</td>
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<td>Bulla</td>
<td>54 species of 26 genera</td>
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<td>Farabgoli et al. 2007</td>
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<td>14 species of 8 genera</td>
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<td>Dajiang</td>
<td>17 species of 16 genera</td>
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<td>Elikah River</td>
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<td>Çüreük dag</td>
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<td>Dongpan</td>
<td>48 species of 28 genera</td>
<td>8 species of 7 genera</td>
<td>*</td>
<td>Yuan et al. 2007</td>
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</table>

Footnote: * means no data. PTTB = Permian-Triassic transitional beds.
Earliest Triassic ostracod fauna of Yangou

Fig. 1

Fig. 2
Earliest Triassic ostracod fauna of Yangou
Earliest Triassic ostracod fauna of Yangou

Fig. 4
Earliest Triassic ostracod fauna of Yangou

Fig. 5
Earliest Triassic ostracod fauna of Yangou

Fig. 6

Fig. 7
Earliest Triassic ostracod fauna of Yangou

Fig. 8

Fig. 9