Ostracod fauna from the Permian–Triassic boundary interval of South China (Huaying Mountains, eastern Sichuan Province): palaeoenvironmental significance

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Abstract

Thirteen species of ostracods in a sample of 400 specimens were extracted by hot acetolysis from three samples within the earliest Triassic Hindeodus parvus zone, in the Permian–Triassic Boundary interval in the Huaying Mountains, eastern Sichuan Province, South China. One new species, Langdaia laolongdongensis n.sp., was found. Ostracod preservation is good. This study provides ostracod data that demonstrate: (a) confirmation of Palaeozoic holdovers in the earliest Triassic in South China; (b) consistency between the palaeoecological interpretation of ostracod faunas and previous environmental and oceanic interpretations, that suggest poorly-oxygenated waters invaded the shelf in the earliest Triassic, and demonstrate the value of ostracods in the analysis of these rocks; and (c) evidence of palaeobiogeographical links are between South China and Turkey, and confirm that South China, Iran, and Turkey remain close from Middle Permian until, at least, the earliest Triassic.

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Keywords: Ostracods; Permian–Triassic boundary interval; South China

1. Introduction and geological setting

The Permian–Triassic Boundary Interval (PTBI) is well-exposed in the Huaying Mountains of Sichuan Province, South China (Fig. 1), where previous studies revealed an unusual crystalline carbonate crust, of possible microbial origin (Kershaw et al., 1999, 2002; Ezaki et al., 2003) between the latest Permian Changxing formation reef facies and the earliest Triassic bedded limestones of the Feixianguan Formation (Fig. 2). In this sequence, the crust sharply overlies the tops of reefs, with possible conformable contact (Fig. 3). Hindeodus parvus conodonts extracted from the sediments near the top of the crust, and up to 50 cm above its upper surface (Kershaw et
al., 2002) demonstrate an early Triassic age, for at least the upper part of the crust; Ezaki et al. (2003) found *H. parvus* at 0.5 m above the base of the crust, but the age of its lowest part is not confirmed; therefore it is possible that the lowest part of the crust is Permian. However, the ostracods described in this paper were extracted from within the *parvus* zone, and are, therefore, all Triassic. The results presented in this paper are the first part of a larger study of ostracods in the PTBI, in an attempt to apply ostracods as palaeoenvironmental indicators, given that they are part of an impoverished fauna which existed immediately after the extinction event.

2. Systematic analysis of ostracod fauna

2.1. Methodology and general characteristics

Three samples from the Feixianguan Formation (earliest Triassic) were analysed for ostracod analy-

sis. Samples L2 and L3b came from Laolongdong locality (see Fig. 1 for location and horizon; details of localities are given in maps provided by Kershaw et al., 1999, 2002, and by Ezaki et al., 2003, and are not repeated in this paper) and B3 from Baizhuyuan (Fig. 1). The samples were processed by ‘hot acetoanalysis’ (Lethiers and Crasquin-Soleau, 1988; Crasquin-Soleau et al., 2005). This technique releases calcareous shells contained in hard limestones. After complete drying, the sample, reduced to small pieces, is covered with pure acetic acid (no effervescence should occur) and placed on a heating sand-bath at a temperature of 60–80 °C. After some time (varying from 1 day up to several weeks), a muddy deposit forms at the bottom of the pot. When sufficient muddy deposit is present, the excess acid is filtered off. The acid acquires a rust colouring but can be re-used with the same efficiency. The samples are then washed. For ostracods, a battery of three sieves is used: the 2-mm mesh retains undisaggregated sediment, the 0.5-mm mesh retains adults and large forms, and the 0.1-mm sieve retains small specimens and larvae. The washing should be quick and the samples rinsed out thoroughly to limit the acid attack which begins immediately. The operator should beware of the strong acid vapours that are released during sieving. The residues, collected in porcelain or Teflon cups, are dried on a sand-bath or in a heating-store. They are then ready for picking (Crasquin-Soleau et al., 2005).

Almost 400 specimens were extracted from the sediments. We recognized 13 species (Plates I and II)
belonging to nine genera. One species is new and is described: *Langdaia laolongdongensis* n.sp.

The distribution of species is summarized in Fig. 5. Three species belong to previously described taxa: *Callicythere postiangusta* Wei Ming, 1981 from the Leikoupo Formation, Middle Triassic in Weiyuan, Sichuan, China, *Bairdiacypris ottomanensis* Crasquin-Soleau, 2004 from the Kokarkuyu Formation, Induan of Western Taurus, Turkey (Crasquin-Soleau et al., 2004a), *Langdaia suboblonga* Wang, 1978 from the Feixianguan and Chayashao Formations, Western Guizhou and Northeastern Yunnan, Early Triassic (Wang, 1978); Qijiang, Hechuan, and Emei of Sichuan (Wei, 1981); Zhenfeng and Zunyi, Guizhou (Hao, 1994, 1992), China. Two other species were previously recognized in other localities, although left in open nomenclature: *Paracypris* sp. sensu Hao, 1992 from the Lower Triassic Feixianguan Formation, Zhenfeng and Zunyi, Guizhou, China, and *Cytherella* sp. sensu Agarwal et al., 1980 (Agarwal et al., 1980) from the Khunamuh Formation, Scythian, Kashmir, Himalaya.

It is important to note that we discovered here three Palaeocopida species (*Langdaia suboblonga*, *Callicythere postiangusta*, and *Bairdiacypris ottomanensis*).
Langdaia laolongdongensis n.sp., and Hollinella sp.1). The Palaeocopida have been considered as an entirely Palaeozoic group and their disappearance as a marker for the Palaeozoic–Mesozoic boundary (although the modern genus Manawa is considered to be a recent relict of this order—Horne et al., 2002). After a discovery of these straight dorsal border ostracods in the Early Triassic of Western Taurus (Turkey; Crasquin-Soleau et al., 2002), a synthesis was drawn on the topic by Crasquin-Soleau et al. (2004b). They showed that 10 species of Palaeocopida survive in the earliest Triassic. Langdaia suboblonga is one of them. The two specimens of Hollinella sp.1 are badly preserved and are insufficient to determine if they belong to one of the four Hollinella species previously recognized in the Early Triassic. In any case, L. laolongdongensis n.sp. brings the number of Mesozoic Palaeocopida to at least eleven. The Palaeocopida are holdovers from the mass extinction, although they are represented by very few species and disappear finally after the Griesbachian.

2.2. New species: Langdaia laolongdongensis n.sp.

The following is a formal description of the new species found in the samples.

Order PALAEOCOPIDA Henningsmoen 1953
Suborder KLOEDENELLOCOPINA Scott 1961
emend. Lethiers 1981
Superfamily KLOEDENELLACEA Ulrich and Bassler 1908
Family KNOXITIDAE Egorov 1950
Genus Langdaia Wang, 1978

Langdaia laolongdongensis n.sp.
Plate II, 7–12.

Etymology: from Laolongdong, the type locality.
Holotype: one complete carapace, figured Plate II, 7, collection number P6M2156.
Paratype: one complete carapace, figured Plate II, 8, collection number P6M2157.
Type level: sample L3B, Feixianguan Formation, earliest Griesbachian, Early Triassic; Laolongdong section, Southeastern Sichuan, South China.
**Diagnosis**: a species of genus *Langdaia* Wang, 1978 with subquadrangular, punctate carapace.

**Description**: carapace subquadrangular; dorsal border long and straight, anterior and posterior borders largely rounded, cardinal angles well expressed, ventral border long and straight or gently concave in its median part in ♀, median sulcus (S2), shallow, located near mid-length and above mid-height; on carapace, median lobe (L2) may be well developed; carapace finely reticulated. Right valve overlaps the left one around all free margins, with maximum in ventral part.

Sexual dimorphism present: heteromorphs, i.e., ♀ (see example on Plate II, 7, 8) have more rectangular carapace, with thicker shell in posterior part, S2 is better expressed; tecnomorphs, ♂ and larvae (see
example on Plate II, 12) have maximum height located in the anterior 1/3 of length and maximum thickness in anterior 1/3 of length.  

Remarks: sexual dimorphism is present as in other species of the genus. This species is only the second described in the genus. The type species of the genus (*Langdaia suboblonga*) was described by Wang (1978) in early Triassic Feixianguan and Chayashao Formations of Western Guizhou and Northeastern Yunnan. *Langdaia suboblonga* was also recognized here (Plate II, 1–6). *Langdaia laolongdongensis* is more quadrangular, has a reticulated shell and shows in some specimens a well developed L2.

Size: \(L=0.59–0.66\text{ mm}; H=0.33–0.37\text{ mm.}\)

Distribution: Samples L2 and L3B, Feixianguan Formation, earliest Griesbachian, Early Triassic; Laolongdong section, Southeastern Sichuan, South China.

3. Palaeoenvironmental analysis and discussion

3.1. Major characteristics

In this palaeoecological analysis, only samples L2 and L3b are taken into account. Sample B3 yielded only 23 specimens belonging to the Bairdiidae, whose precise determination was not possible.

The ostracod fauna contained in the two other samples is characteristic of warm water platform deposits, consistent with the sedimentological interpretation of the site. The Bairdiacea are present in shallow to deep, open carbonate environments with normal salinity. The Kloedenellacea are considered to be inhabitants of very shallow, euryhaline environments. The large species of Hollinacea with developed adventral structures can characterize environments such as interdistributary bays, prodelta and interdeltaic embayments and lagoons. In both samples, the palaeopsychrospheric species, markers of deep marine environments, below the slope break are absent.

The assemblage of samples, L2 is the most diverse, both in specimens (199) and in species (12). It is composed of 58.33% Bairdiidae (*Bairdia, Acratia, Bairdiacypris, Paracypris*), 16.66% Kloedenellacea (*Langdaia*), 8.33% Hollinacea (*Hollinella*), and 16.33% of other neritic species. At present, the genera *Callicythere* and *Cytherella* are still not palaeoecologically characterized. In any case, the composition of this ostracod assemblage indicates an open marine environment, with relatively stable conditions. Of considerable interest, however, is the fact that the assemblage was deposited in sediments that suggest very unusual ocean conditions in these earliest Triassic rocks.
The assemblage of sample L3B is less diverse than L2, with 167 specimens and 5 species: 4% Bairdiidae (with **Bairdia** only), 40% Kloedenellacea (**Langdaia**) and 20% of other neritic species. The ostracod assemblage indicates a more proximal position on the platform, shallower (<50m), with an environment subjected to variations of salinity and/or bathymetry. However, this sample is from the topmost part of the microbialite crust (Fig. 3) and, therefore, an alternative interpretation is that the facies represents a depleted oxygen content of the water, which is consistent with the sedimentological interpretations provided by Kershaw et al. (1999, 2002) and Ezaki et al. (2003). Kershaw et al. (1999) suggested that poorly oxygenated water supersaturated with bicarbonate upwelled onto the shelf, leading to precipitation of the unusual carbonate structure of the crust. However, the crust ceases sharply, and is overlain by bedded limestones (Fig. 3), with little apparent erosion of the crust upper surface, because of its well-preserved dome-shaped upper surface in most locations. Ezaki et al. (2003) recorded some evidence of erosion, but the overall impression is that the crust stopped forming abruptly. Ostracods from the overlying sample L2 represent a different assemblage.

### 3.2. Oxygen levels in the seawater

In 1994, Lethiers and Whatley proposed a model to approximate the oxygen level of Late Palaeozoic marine waters by use of ostracods. Previously, Whatley (1990, 1992) demonstrated a relationship between the modes of alimentation (feeding) and respiration in certain post-Palaeozoic ostracods. He showed that, in contrast to deposits feeders, filter-feeding ostracods create a permanent and enhanced circulation over their ventral respiratory surface by virtue of their larger number of branchial plates. Fine particles in suspension are filtered by special tufts of setae and transported, both forwards and backwards to the mouth. This form of alimentation confers a threefold advantage on such ostracods during times or in places where oxygen levels are low. In dysoxic conditions, more water will be passed through the cuticle surface and increase the access to available oxygen and improve their survival potential. Filter feeders incubate their eggs and retain the first instars within the carapace, thus conferring to them the same survival benefits. In times of lowered oxygen levels, the presence of more abundant suspended organic particles will further benefit the filter feeders. The preferential survival and enhanced importance of filter feeders has been shown during various kenoxic (the term kenoxic is used to denote an event when oxygen levels were reduced). Most of so-called anoxic events, for which the name implies total deprivation of oxygen were, in fact, kenoxic events in the Cenomanian–Turonian (Jarvis et al., 1988; Babinot and Crumière-Arnaud, 1990; Whatley, 1990, 1992; Whatley et al., 2003), in the Liassic (Boomer and Whatley, 1992), and in Palaeogene (Whatley and Arias, 1993).

Lethiers and Whatley (1994) demonstrated that this is also true in the Palaeozoic. They analysed 43 localities between the Emsian and Visean where the sedimentological and palaeontological data are well known and where the changes in oxygen levels could not be explained by variations neither of global climate changes, nor oceanic circulation and local variations in energy levels. They demonstrated the increase of filter feeders when oxygen levels fall and vice-versa. Neritic filter feeding ostracods of the Late Palaeozoic and Early Triassic comprise the Palaeocopida, with Paraparchitacea and Kloedenellacea, Platycopida and Metacopida. Deposit feeders comprise the Podocopida with the Bairdiocypridacea and the Bairdiaceae.

The Lethiers and Whatley (1994) interpretative model, presented in Fig. 4, allows the determination of approximate oxygen levels in neritic environments using the percentage of filter feeding ostracods. When the percentage of filter feeding ostracods reaches 60% the oxygen concentration should be around 3.5–3.6 ml/l. If the percentage exceeds 85–90%, kenoxia may have been reached. When anoxia is total, no ostracods should survive. Applying the Lethiers and Whatley model (1994) in this study shows consistency with the suggestion that carbonate-rich poorly-oxygenated water upwelled onto the shelf, providing the supersaturation of shallow waters to precipitate the microbialite deposits described by Kershaw et al. (1999). In sample L2, we recognized 41.7% of filter feeder species and 60% in sample L3B (Fig. 5). If we compare this data with the Lethiers and Whatley (1994) model (Fig. 4), we interpret for sample L2, an oxygen concentration around 4.7–4.8 ml/l, and for...
sample L3B, an oxygen concentration around 3.2–3.3 ml/l on the boundary with dysoxia. Fig. 4 shows that the oxygen level of sample L3B (in the crust) is lower than that of sample L2 (above the crust), suggesting that oxygen levels increased in the ocean after the crust formation was terminated. Kershaw et al. (1999, 2002) discussed the reason for the abrupt cessation of crust formation, but could not confirm a mechanism for the apparent “switching off” of the crust formation. However, if upwelled poorly oxygenated supersaturated water was the source of carbonate for the crust, then it is logical that switching off the supply would lead to increased oxygenation, recorded by the ostracods.

Normal marine water typically contains 5–6 ml/l at the surface, but in modern seas, this falls to 1 ml/l in the oxygen minimum zone between 500 and 1000 m water depth (Garrison, 1998, p. 321). The depth of water in the early Triassic facies of Sichuan is not determined, although Kershaw et al. (1999) argued that the water was shallow, and not more than 65 m, on the basis of oncoids found in sediments above the

<table>
<thead>
<tr>
<th>Environments</th>
<th>Biotrope</th>
<th>open carbonate platform</th>
<th>+/- restricted</th>
<th>Mud zones</th>
<th>Black shales</th>
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<tr>
<td>Specimen abundance</td>
<td>+/- high according to energy levels</td>
<td>++ very high</td>
<td>++ very low</td>
<td></td>
<td></td>
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<tr>
<td>Percentage of filter-feeding species</td>
<td>10 20 30 40 50 60 70 80 90</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Approximate oxygen concentration (ml/l)</td>
<td>6 5 4 3 2 1 0.5</td>
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<tr>
<th>Sample</th>
<th>Number of specimens</th>
<th>Filter-feeding ostracod species</th>
<th>% filter-feeding ostracod species</th>
<th>Deposit feeder species</th>
<th>% of deposit feeder species</th>
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</thead>
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<tr>
<td>L3B</td>
<td>167</td>
<td>3</td>
<td>60%</td>
<td>2</td>
<td>40%</td>
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<tr>
<td>L2</td>
<td>199</td>
<td>5</td>
<td>41.7%</td>
<td>7</td>
<td>58.3%</td>
</tr>
<tr>
<td>B3</td>
<td>23</td>
<td>0</td>
<td>0%</td>
<td>3</td>
<td>100%</td>
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<th>Species</th>
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<th>L3B</th>
<th>B3</th>
<th>Alimentation and respiration mode</th>
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<td>Acratia sp.1</td>
<td>X</td>
<td></td>
<td></td>
<td>Deposit feeder</td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Bairdia sp.2</td>
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<td>X</td>
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<tr>
<td>Bairdia sp.3</td>
<td></td>
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<td>Deposit feeder</td>
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<tr>
<td>Bairdiacypris ottomanensis Crasquin-Soleau 2004</td>
<td>X</td>
<td>X</td>
<td>Deposit feeder</td>
<td></td>
</tr>
<tr>
<td>Bairdiacypris sp.1</td>
<td>X</td>
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<td></td>
<td>Deposit feeder</td>
</tr>
<tr>
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<td>X</td>
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<tr>
<td>Bairdiidae indet.</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Deposit feeder</td>
</tr>
<tr>
<td>Callicythere postiangusta Wei Ming, 1981</td>
<td>X</td>
<td>X</td>
<td>Filter-feeding ostracod</td>
<td></td>
</tr>
<tr>
<td>Cytherella sp.</td>
<td>X</td>
<td></td>
<td></td>
<td>Filter-feeding ostracod</td>
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<tr>
<td>Hollinella sp.1</td>
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<tr>
<td>Langdaia laolongdongensis n.sp.</td>
<td>X</td>
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<td></td>
<td>Filter-feeding ostracod</td>
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<td>Langdaia suboblonga Wang, 1978</td>
<td>X</td>
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<td></td>
<td>Filter-feeding ostracod</td>
</tr>
<tr>
<td>Paracypris sp. sensu Hao, 1982</td>
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<td>X</td>
<td></td>
<td>Deposit feeder</td>
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Fig. 4. The Lethiers and Whatley (1994) proxy model of oxygen levels linked to ostracod abundance and type, with the estimations of oxygen levels of the samples processed in this study (L2 and L3B). Note that the oxygen levels interpreted are not as fully oxygenated as typical marine waters; see text for discussion.

Fig. 5. Tables of species abundances and feeding types of ostracods from samples in this study. See text for discussion.
crust (see Fig. 3). The results from the ostracod fauna are in agreement with this data. However, solubility also depends on temperature, so that at 10 °C solubility of oxygen is 6.42 ml/l at atmospheric pressure, compared to 5.26 ml/l at 20 °C, falling to 4.41 ml/l at 30 °C (Garrison, 1998, p. 320). Although arguments exist that seawater temperature was higher in the Palaeozoic (Tucker and Wright, 1990, p. 417), if we assume that the seawater was of normal tropical temperatures of not less than c. 20 °C, then a dissolved oxygen level of 5–6 ml/l may be expected. Note also that the location of the South China Block at that time was in very low palaeolatitude, in shallow water and at a time period where the increase of global temperature are likely to have been higher than 20 °C. Of course, uncertainties remain in the strict comparison between Early Triassic and modern sea waters, and the given values have to be taken with all the necessary precautions.

4. Paleobiogeographic relationships

During the Middle Permian, the palaeobiogeographical links between South China and the southwestern part of Palaeo-Tethys/Neo-Tethys (Fig. 6), during the Middle–Late Permian, are now well established on the base of research conducted on ostracods of the Arabian plate (in Oman; Crasquin-Soleau et al., 1999, Crasquin-Soleau et al., 2001; in Saudi Arabia; Crasquin-Soleau et al., 2005, in press) and in Western Taurus (Turkey; Crasquin-Soleau et al., 2004a,b). The results obtained here, even based on a small sample, suggest that these links remain during the earliest Triassic. Indeed, the species Bairdiacypris ottomanensis Crasquin-Soleau 2004 is also present both in Turkey. This species is also recognized at the base of the Triassic Elikah Formation in North-Central Elbourz (Iran; ongoing work). This species is benthic and its larvae have the same way of life, i.e. its dispersion should take place along the platform where the palaeoecological conditions (temperature, bathymetry, salinity) stay equivalent. This implies that these areas should be closely located and, as for the Permian (Crasquin-Soleau et al., 1999), the Pangaea B configuration, which reduces the oceanic space between Arabian Plate, Iran, and South China, should be favoured.

5. Conclusion

This study provides ostracod data that demonstrate:

1. Confirmation of Palaeozoic holdovers in the earliest Triassic in South China;
2. Consistency between the palaeoecological interpretation of ostracod faunas and previous environmental and oceanic interpretations, demonstrating the value of ostracods in the analysis of these rocks.
3. Adaptation ability of this group to re-colonize biotopes after mass extinction events. Ostracods are the very first organisms with micro-gastropods and micro-foraminifera (Baud et al., 1997) discovered in the earliest Triassic.

Fig. 6. Palaeogeographical reconstruction of Pangaea B during Middle Permian (modified after Crasquin-Soleau et al., 2001).
4. Close palaeobiogeographical links displayed during the Permian between South China and south-western Tethys remain during the earliest Triassic.

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References


