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Trace fossil evidence for restoration of marine ecosystems following the end-Permian mass extinction in the Lower Yangtze region, South China

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ABSTRACT

Unlike the high-abundance, low-diversity macrofaunas that characterize many Early Triassic benthic palaeocommunities, ichnofossils were relatively common in the aftermath of the end-Permian mass extinction worldwide. Ichnofossils therefore are a good proxy for ecosystem recovery after the end-Permian biotic crisis. This paper documents 14 ichnogenera and one problematic form from Lower Triassic successions exposed in the Lower Yangtze region, South China. Post-extinction ichnodiversity remained rather low throughout the Griesbachian–early Smithian period and abruptly increased in the late Smithian. However, several lines of evidence, including extent of bioturbation, burrow size, trace-fossil complexity, and tiering levels, indicate that diversification of ichnotaxa in the late Smithian did not signal full marine ecosystem recovery from the Permian/Triassic (P/Tr) mass extinction. Marine ichnocoenoses did not recover until the late Spathian in South China. The marginal sea provided hospitable habitats for tracemakers to proliferate in the aftermath of the end-Permian mass extinction.

1. Introduction

As the largest Phanerozoic extinction event, the Permian/Triassic (P/Tr) mass extinction not only severely impacted biodiversity (Bambach et al., 2004), but also profoundly degraded marine ecosystems to ones characterized by high-abundance, low-diversity skeletonised metazoan communities (Bottjer et al., 2008). There is some evidence that global marine biodiversity did not recover until the early Middle Triassic (Erwin and Pan, 1996), perhaps 5 million years after the mass extinction (Lehrmann et al., 2006). Biotic recovery after the P/Tr crisis is believed to be much delayed due to devastating environmental conditions prevailing in the Early Triassic oceans (see references in Bottjer et al., 2008). Accordingly, the recovery of the devastated ecosystems has attracted an increasing number of multidisciplinary studies to reveal the tempo and mechanisms of recovery after the P/Tr crisis (e.g., Payne et al., 2004; Twitchett, 1999, 2006; Tong et al., 2007). Palaeoecologic methods are powerful tools to study biotic crises and their subsequent recovery (Twitchett, 2006 and references therein). In particular, trace-fossil assemblages can be crucial to revealing the timing and pattern of ecologic recovery following mass extinctions because post-extinction macrofaunas can be unevenly distributed and poorly preserved (Fraiser and Bottjer, 2005; Fraiser et al., 2010).

Several recent ichnological studies have greatly enhanced our understanding of ecologic recovery following the P/Tr mass extinction (Beatty et al., 2005, 2008; Fraiser and Bottjer, 2009; Pruss and Bottjer, 2004; Twitchett, 1999; Twitchett and Barras, 2004; Twitchett and Wignall, 1996; Zonneveld et al., 2002, 2004, 2010). However, most of the trace fossil-based studies concerning the Early Triassic ecologic recovery are based on data derived from North America (Fraiser and Bottjer, 2009; Pruss and Bottjer, 2004; Twitchett and Barras, 2004), western Tethys (Twitchett, 1999; Twitchett and Wignall, 1996), or northern high-latitude regions (Beatty et al., 2005, 2008; Wignall et al., 1998; Zonneveld and Beatty, 2007; Zonneveld et al., 2002, 2004, 2010). Very little has been published on the trace fossils from South China as proxies of ecosystem recovery following the P/Tr crisis, although a few localized Early Triassic ichnoassemblages have been described (Bi et al., 1995, 1996; Liu and Wang, 1990; Luo et al., 2007; Yang, 1988; Wang, 1987; 1997).

This paper aims to document Early Triassic ichnotaxa in the Chaohu and neighbouring Yashan areas, and to evaluate marine ecosystem recovery following the P/Tr crisis using trace fossil assemblages as proxies. Abundant new trace fossils from the Lower Triassic successions in the Chaohu and neighbouring Yashan areas (Fig. 1A) are described herein, and the previously published data of the Lower Triassic trace fossils from the Lower Yangtze region (Bi et al., 1995, 1996; Liu and Wang, 1990) are also critically reviewed and revised (Table 1).

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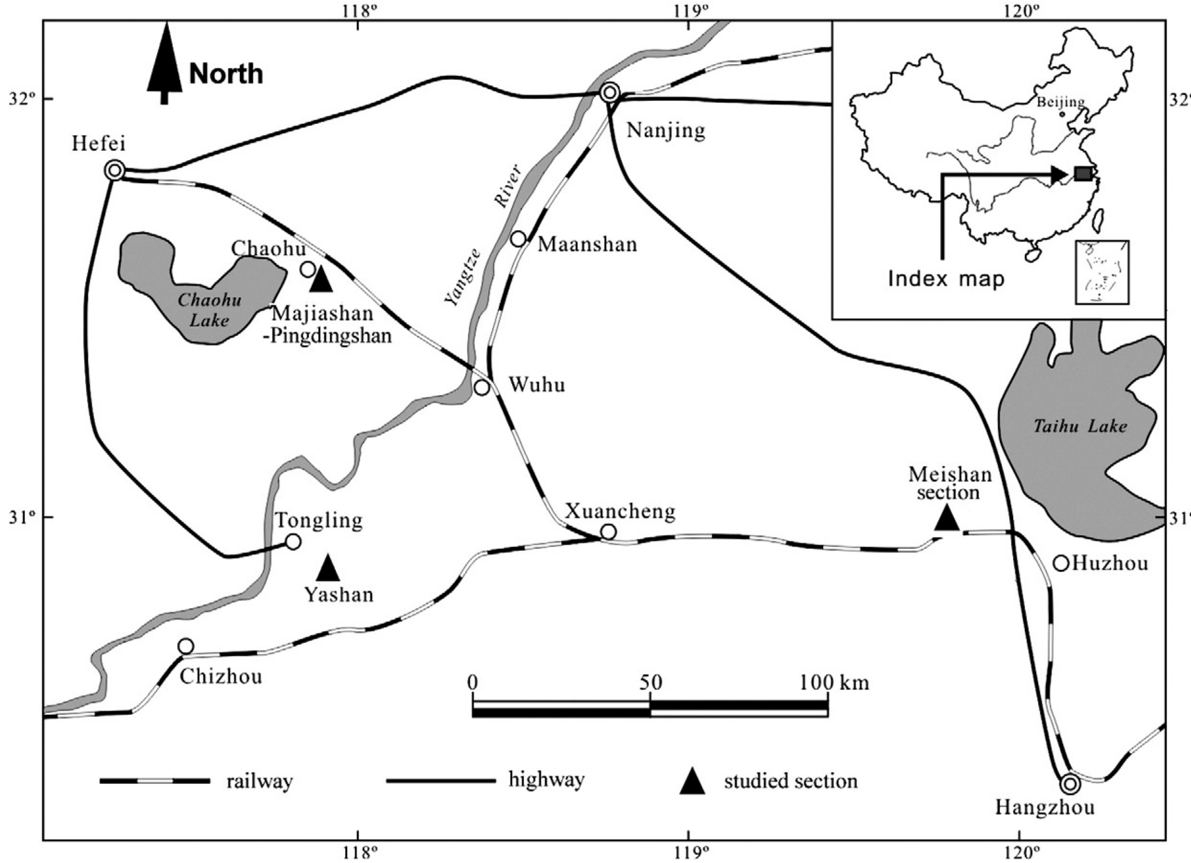

Fig. 1. Location of the West Pingdingshan–Majiashan section, Chaohu and the Yashan section, Nanling, Anhui Province, South China.

2. Geological setting, studied sections, and stratigraphical distributions of ichnotaxa

2.1. Geological and stratigraphical settings

Lower Triassic rocks are widely distributed cross the entire South China block (Tong and Yin, 2002). The P/Tr boundary beds and Lower Triassic successions are particularly complete in the Lower Yangtze region including southern Anhui, southern Jiangsu, northern Jiangxi and western Zhejiang Provinces (Fig. 1). Sound biostratigraphy in combination with high-resolution isotopic geochemistry and abundant skeletonised fossils enabled us to analyze the recovery of marine ecosystems following the P/Tr mass extinction in the Chaohu area (Chen et al., 2010; Tong et al., 2007).

During the P/Tr transition, the South China block was located near the tropical zone at the eastern part of the Tethys Ocean (Ziegler et al., 1998). The uppermost Permian to Lower Triassic marine successions are well-exposed in the Lower Yangtze region. Here, the Lower Triassic successions are comprised of the Yinkeng, Helongshan and Nanlinghu Formations in ascending order, which correlate well with one another from place to place in this region. The Yingkeng Formation is Griesbachian to early Smithian in age, while the Helongshan and Nanlinghu Formations are late Smithian and Spathian in age, respectively (Figs. 2 and 3). The uppermost Permian sediments were accumulated primarily in shelf settings and are represented by the Talung Formation, except for several localities (i.e., Huangzhishan section) that record a platform succession at the end of the Permian (Chen et al., 2009, 2010). Overall, the Lower Triassic succession is dominated by siliciclastics at its lower part and carbonates at its upper part. Complete conodont, ammonoid and bivalve zones have been established throughout the entire Lower Triassic successions in most localities (Chen et al., 2002, 2010; Tong and Yin, 2002). In particular, high-resolution biostratigraphy has been undertaken for the Triassic in the Chaohu areas, Anhui Province, South China (Fig. 1A) since the 1990s (Tong et al., 2003, 2004, 2005; Zhao et al., 2007; L. Zhao et al., 2008; Fig. 2). Thus, the Lower Triassic succession of Chaohu was referred to as the standard succession for Lower Triassic correlations within South China (Tong et al., 2003).

2.2. West Pingdingshan and southern Majiashan sections

The West Pingdingshan (WP) and Majiashan (MJS) sections are situated in a southeastern suburb of the city Chaohu, Anhui Province, South China (Figs. 1 and 4A). Here the Upper Permian to Lower Triassic succession is comprised of marine sediments and underlies Middle Triassic evaporitic dolomites (Tong et al., 2003, 2005; Fig. 2). The P/Tr boundary beds and the lower part of the Lower Triassic succession are well exposed at the western slope of Pingdingshan Hill (Fig. 4B and C). The upper Lower Triassic succession is better exposed at the southern slope of the Majiashan Hill, about 2 km away from Pingdingshan Hill (Tong et al., 2003, 2005, 2007; Zhao et al., 2007; L. Zhao et al., 2008).

The West Pingdingshan section records the complete P–Tr and Induan–Olenekian boundary successions and yields abundant conodont, ammonoid, bivalve, and brachiopod faunas, and thus was nominated as a candidate of the Global Stratotype Section and Point (GSSP) for the Induan–Olenekian boundary (Tong et al., 2003). The Permian Talung Formation is 4–5 m thick and consists of black mudstone and cherty shale yielding deep-water facies conodonts, radiolarians, ammonoids, bivalves, and brachiopods of Changhsingian age (Peng et al., 2001; Yin et al., 1995; Zhang et al., 1992). The P/Tr boundary beds at West Pingdingshan are comprised of a white claystone layer (Bed 3), a black shale bed (Bed 4), a yellow, medium-