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Invited research article

Sedimentology and ichnology of two Lower Triassic sections in South China: Implications for the biotic recovery following the end-Permian mass extinction

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ABSTRACT

Biotic recovery following the end-Permian mass extinction was investigated using trace fossil and facies analysis of two Lower–Middle Triassic sections in South China. The Susong section (Lower Yangtze Sedimentary Province) comprises a range of carbonate and mudstone facies that record overall shallowing from offshore to intertidal settings. The Tianshengqiao section (Upper Yangtze Sedimentary Province) consists of mixed carbonate and siliciclastic facies deposited in shallow marine to offshore settings. Griesbachian to Dienerian ichnological records in both sections are characterized by low ichnodiversity, low ichnofabric indices (1–2) and low bedding plane bioturbation indices (1–2). Higher ichnofabric indices (3 and 4), corresponding to a dense population of diminutive ichnotaxon, in the Tianshengqiao section suggest opportunistic infaunal biotic activity during the earliest Triassic. Ichnological data from the Susong section show an increase in ichnodiversity during the late Smithian with 11 ichnogenera identified and increased ichnofabric indices of 4–5 and bedding plane bioturbation indices of 3–5. Although complex traces such as *Rhizocorallium* are present in Spathian-aged strata in this section, low ichnodiversity and ichnofabric indices and diminutive *Planolites* suggest a decline in recovery. In the Tianshengqiao section, ichnofabric indices are moderate to high (3–5) although only six ichnogenera are present and *Planolites* burrows are consistently small in Smithian and Spathian strata. Complex traces, such as large *Rhizocorallium* and *Thalassinoides*, and large *Planolites*, did not appear until the Anisian. Ichnological results from both sections record the response of organisms to unfavourable environmental conditions although the Susong section shows earlier recovery during the Smithian prior to latest Smithian–Spathian decline. This decline may have resulted from a resurgence of euxinic to anoxic marine environment in various regions of South China. Ichnological data from the Tianshengqiao section indicate protracted recovery throughout the Early Triassic as previously found elsewhere in South China. Comparison of the South China trace fossil records with global ichnological data show a diachronous pattern of recovery of trace makers and highlights the heterogeneous development of oxic facies on the marked variation in recovery rate.

1. Introduction

The end-Permian mass extinction (EPME) is considered to record the largest diversity loss and to have been the most severe in its ecological impact on both the marine and continental ecosystems through the last 550 Myr of Earth history (McGhee et al., 2004). The EPME decimated approximately 90% of marine invertebrate and ~80% of terrestrial vertebrate taxa (Erwin et al., 2002; Erwin, 2006). Subsequent biotic recovery took up to eight million years (Benton et al., 2014) such that it was not until the early Middle Triassic that the marine ecosystem structure recovered fully (Erwin, 2006; Chen and Benton, 2012; Benton et al., 2014). Studying the consequences and causes of the Permian–Triassic (P–Tr) extinction helps develop understanding of the responses and evolutionary mechanisms of ecosystems through extreme environmental changes. The EPME and subsequent recovery have been widely studied with key questions regarding extinction mechanisms and recovery processes remaining open for continued research (Chen and Benton, 2012; Foster and Twitchett, 2014).

Studies of trace fossils as a means of deciphering patterns of biotic recovery after the EPME have proved useful (e.g. Twitchett and

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Wignall, 1996; Twitchett, 2006; Pruss and Bottjer, 2004; Twitchett and Barras, 2004; Knaust, 2010; Chen et al., 2011, 2012; Hofmann et al., 2011; Mata and Bottjer, 2011; Shi et al., 2015; Zhao et al., 2015). Trace fossils record organism–substrate interactions, thus serving as good proxies for larger processes operating within ancient trophic systems (Morrow and Hasiotis, 2007). Trace fossils represent the activities of both skeletonized as well as soft-bodied organisms. Soft-bodied organisms account for a large percentage of the total biomass within marine ecosystems (Allison and Briggs, 1991; Sperling, 2013), but are typically only preserved in the form of trace fossils. Hence trace fossils potentially provide more complete records of both infaunal and epifaunal organisms, thus facilitating the study of community structures and composition (Morrow and Hasiotis, 2007). Furthermore, trace fossils provide invaluable information regarding biotic perturbations that are not readily available through geochemical, sedimentological and modeling-based research (e.g. Morrow and Hasiotis, 2007; Zonneveld, 2011).

Trace fossils are commonly preserved in Lower Triassic strata around the world, and their preservation would not have been affected by environmental conditions such as ocean acidification that may have existed in the immediate aftermath of EPME (e.g. Woods and Bottjer, 2000; Zonneveld, 2011). This advantage highlights the importance of trace fossil studies in documenting Early Triassic recovery.

Advances in high-resolution biostratigraphy in Lower Triassic strata worldwide underpin detailed documentation of sedimentological, geochemical and biological changes through the Early Triassic recovery interval. Ichnological studies have been undertaken on Lower Triassic strata from equatorial to mid- and high-latitude regions that are conventionally grouped into three zones around the Panthalassan, Boreal and Paleotethyan Oceans (Fig. 1A). Numerous Lower and Middle Triassic trace fossil assemblages have been documented from different stratigraphic units in South China, most of which are part of widespread carbonate platforms developed in the eastern Paleotethys Ocean (e.g. Yang and Sun, 1982; Liu and Wang, 1990; Yang et al., 1992; Bi et al., 1995, 1996; Wang, 1997; Chen et al., 2011 and references therein). Previous ichnological studies in these areas focused on ichnotaxonomy and paleoenvironmental interpretation (e.g. Liu and Wang, 1990; Yang et al., 1992; Wignall et al., 1998; Bi et al., 1995, 1996; Wang, 1997). However, only a few studies have examined the timing and pattern of Early

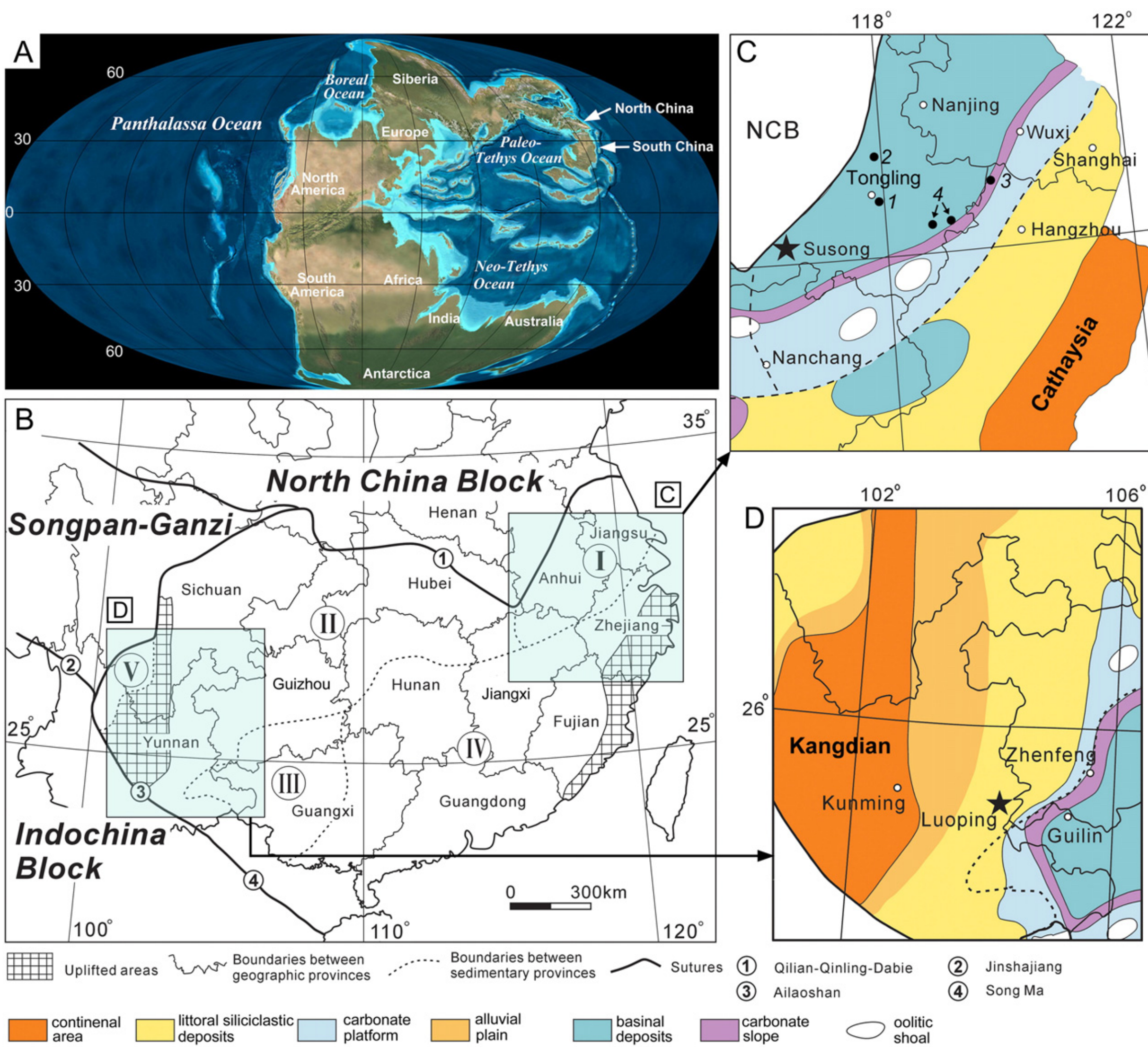

Fig. 1. A) Global paleogeography in the late Early Triassic. B) Location of the South China Craton showing the five Early Triassic sedimentary provinces. I: Lower Yangtze, II: Upper Yangtze, III: Youjiang, IV: Cathaysia, V: Lijiang. C) Early Triassic paleogeography in the studied Susong area. D) Early Triassic paleogeography in the studied Tianshengqiao area. Stars in C and D represent locations of the studied sections in Susong and Tianshengqiao respectively. Note localities with detailed trace fossil studies from Lower Yangtze are also indicated in C (solid black dots). 1) Majiashan and Pingdingshan (Chen et al., 2011). 2) Yashan (Chen et al., 2011). 3) Meishan (Zhao and Tong, 2010). 4) Jingxian-Ningguo (Liu and Wang, 1990).
(Base map in panel A is from Ron Blakey's Mollweide map at http://www2.nau.edu/rcb7/mollglobe.html. Panel B is modified from Tong and Yin (2002). Panels C and D were modified from Feng et al. (1997).)