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# Two episodes of evolution of trace fossils during the Early Triassic in the Guiyang area, Guizhou Province, South China

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ABSTRACT

The Lower Triassic of the Guiyang area of southern China contains abundant and well-preserved trace fossils, which are useful in the reconstruction of ecological conditions following the end-Permian mass extinction. A total of 16 ichnogenera and 22 ichnospecies were identified; their vertical distribution and evolution indicate that benthic ecosystems experienced two periods of episodic recovery after the P–T event. Episode 1 occurs in the Daye Formation during the Dienerian, when trace-makers first appear in the upper portion of Member D1. Member D2 exhibits the first abrupt increase in ichnodiversity, and trace-makers shift from simple to complex, and undergo a substantial increase in size. These trends indicate a strong capability to rework sediments and an improvement of feeding strategies of trace makers, and points to the development of an early, initial, benthic ecosystem. Despite the emergence of complex trace fossils in D2, such as *Phycodes* and *Phycosiphon*, most of the trace fossils are small, horizontal burrows that are not fully developed in three dimensions. By the end of Dienerian, the regional environment deteriorated, and the benthic ecosystem was destroyed, as evidenced by the disappearance of trace fossils from upper D3 to lower A1, which also corresponds to a marked negative shift of $\delta^{13}C_{carb}$. As a result, this newly established benthic ecosystem was vulnerable. Episode 2 occurs from the late Smithian to the Spathian. Trace fossils reappear in the lower Anshun Formation. The trace fossils from this stage are larger, more complex, and are fully three-dimensional. Trace maker diversity increases from single polychaeta, followed by the appearance of crustaceans, as represented by *Rhizocorallium* in Member A3 of the Anshun Formation. During this period, the marine environment improved and benthic organisms gradually established a basis for a new benthic ecosystem. The marine benthic communities had a transformative effect on the ecological environment of the ocean bottom and played an essential role in paving the way for the recovery of other organisms. Two episodes of evolution of trace fossils reflect that initial restoration of benthic ecosystems was apparently reset at least once during the Early Triassic, recovery was not delayed because of persistent environmental stress but short episodes of deleterious conditions. Marine benthic ecosystems had a full and lasting recovery occurred at the global scale during the Spathian, when oceanographic conditions ameliorated and allowed the recovery of ecosystems worldwide.



## 1. Introduction

The end-Permian mass extinction was the most severe biocrisis of the Phanerozoic (Erwin et al., 2002; Irmis and Whiteside, 2011), and led to the collapse and replacement of Paleozoic filter-feeder, epibenthos-dominant marine ecosystems by a new, mobile benthos-, infauna- and predatory fauna-dominant marine ecosystem (Sepkoski, 1982; Tong and Yin, 2009). The recovery of marine ecosystems has been viewed as more protracted than that following other mass extinctions (Hallam, 1991; Erwin, 1993, 2001; Payne et al, 2011), and this period of stasis lasted over 5 Ma (Lehrmann et al., 2006; Bottjer et al., 2008). But benthic data now increasingly support a multiple crises scenario on an interregional scale (Hautmann et al., 2011; Hofmann et al., 2011, 2014), recovery was much more volatile with the nekton recovering much faster (Orchard, 2007; Brayard et al., 2009), and studies recently have shown that trace fossil indicative of advanced recovery states occur during the Griesbachian (Beatty et al., 2005; Fraiser and Bottjer, 2009; Knaust, 2010; MacNaughton and Zonneveld, 2010; Zonneveld et al., 2010; Chen et al, 2011; Hofmann et al., 2011). Southern China is one of the regions where the Permian–Triassic transition has a complete stratigraphic record and one of the most abundant fossil records in the East Tethys and in the world (Wang, 1987, 1997; Luo et al., 2007; Shi et al, 2008). There are abundant trace fossils preserved in the Lower Triassic Daye Formation and Anshun Formation in the Guiyang area of southern China, and these fossils not only provide a

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wealth of research material related to biological ecosystem recovery and reconstruction, but also have sedimentary sequence continuity with the "Qingyan Biota" of the Middle Triassic in this area. The "Qingyan fauna" shows typical Mesozoic biota and ecological radiation characteristics (Yin et al., 2007; Tong and Yin, 2009; Chen et al., 2010), the benthic ecothic ecosystem recovery from trace fossils herein is prelude of "Qingyan fauna"; through the study of trace fossils from the Guiyang region, this paper analyzes and discusses the initial recovery of marine benthic ecosystems after the end-Permian biotic crisis in the Guiyang region, Guizhou Province, South China.

## 2. Stratigraphy and distribution of trace fossils

Guizhou Province is a part of the South China Block, which was located in the equatorial eastern Tethys during the Early Triassic (Chen et al., 1994; Tong and Yin, 2002). Guiyang city is located on the northern margin of the Nanpanjiang Basin and southwestern margin of the Yangtze Platform (Fig. 1), a transitional setting between a shallow-water carbonate platform and a deep-water basin in the Early Triassic (Enos et al., 1997; Lehrmann et al., 2001, 2003, 2005). Continuous Upper Permian–Lower Triassic strata were deposited in this region (Fig. 2) and include bioclastic limestones of the Upper Permian Changxing Formation, black chert of the Upper Permian to Lower Triassic Dalong Formation, mudstones and limestones of the Lower Triassic Daye Formation and dolomites of the Lower Triassic Anshun Formation. The sedimentary rocks of this region provide a complete record of environmental deterioration, the end-Permian extinction, and the recovery of benthic ecosystems during the Early Triassic.

The Daye Formation is distributed over the largest area compared other formations of the Triassic. According to lithological differences, the Daye Formation can be divided into three members in the Guiyang area (D1, D2 and D3 in ascending order). Member D1, also referred to as the Shabaowan Member, is comprised of predominantly gray-black siliciclastic mudrock that is interbedded with limestones; the mudrock becomes more calcareous toward the top of the section and is also interbedded with tuff layers. The uniformly fine grain sizes and lack of hydrodynamic sedimentary structures in this member indicate deposition in a low-energy setting that was accompanied by volcanic activity. Conodont biostratigraphy (Qin et al., 1993; Chen et al., 2010; Yang et al., 2012) shows that the siliceous mudrocks that comprise the lower portion of D1 are Griesbachian in age (i.e., earliest Triassic), while the upper limestones and mudstones of D1 are Dienerian in age. D1 also yields small fossils such as thin-shelled bivalves (*Claraia* spp.) and ammonoids (*Ophiceras* spp.), which are characteristic "opportunistic species", and form a high-abundance, low-diversity community. The abundance of pelagic nekton-dominated marine fauna (*Ophiceras* spp.) and sedimentary structures suggest deep water and low energy along the northern margin of the Nanpanjiang Basin (Guizhou Bureau, 1987; Enos et al., 2006). Two ichnogenera, *Planolites montanus* and *Palaeophycus curvatus* (Fig. 3A, B), are found in the uppermost portion of D1 in the Gaimao section (43 m above the base of D1), which have small burrow diameters (1 to 3.5 mm in diameter) and a simple structure. D2 mainly consists of thin-bedded medium-gray flaggy limestones with frequent flute casts, which are packaged into intervals of varying bedding thickness that range from 8 mm to several decimeters; in addition, several beds of vermicular limestone (Woods, 2009, 2014) appear in the lower portion of this member. The flaggy limestones formed on a very gentle slope transition between the platform and basin, thin beds, good lamination, dark shades and vermicular limestone indicate relatively deep and less oxygenated waters. Benthic communities developed gradually in this member. Trace fossils show more complex patterns than in D1 (Figs. 3C–J and 4A–B), including branched, reticular, radial, and rule-based meandering fodinichnia including: *Beaconichnus darwinum*, *Chondrites* sp., *Phycodes circinatus*, *Phycosiphon incerta*, *Planolites beverleyensis*, *Pl. montanus* and *Pa. curvatus* as well as crawling traces (*Gordia marina*), pascichnia (*Cosmorhaphe* isp., *Megagrapton irregulare*), domichnia (*Thalassinoides suevicus*), resting traces (*Glockerichnus* isp., and *Mammillichnis aggeris*), and swimming trails (*Undichna* isp.). D3 of the Daye Formation is characterized by medium-bedded limestone, oolitic grainstone and carbonate breccias. Several oolitic packstones with skeletal fragments and lime mudstone clasts are interbedded with breccia near the top of this member. The sedimentology of this unit reflects that sea level lowered and the slope steepened. Bioclastic components of the limestone in D3 comprise a larger portion of the rock, and are dominated by microbivalves. D3 contains trace fossils including: *Pl. beverleyensis*, *Rhizocorallium commune*, *Thalassinoides paradoxicus*, and *Bergauria perata* (Fig. 4C–F).

The Anshun Formation is typically highly dolomitized. The presence of the conodonts *Neogondolella pingdingshanensis* and *Neospathodus. waageni* suggest a Smithian to Spathian age for the Anshun Formation (5 km southwest of the Gaimao section) (Qin et al., 1993; Chen et al., 2010). The Anshun Formation can be divided into 4 members according to changes in lithology (in ascending order: A1, A2, A3 and A4). A1 consists mainly of medium-bedded, algal-laminated dolomite with a few

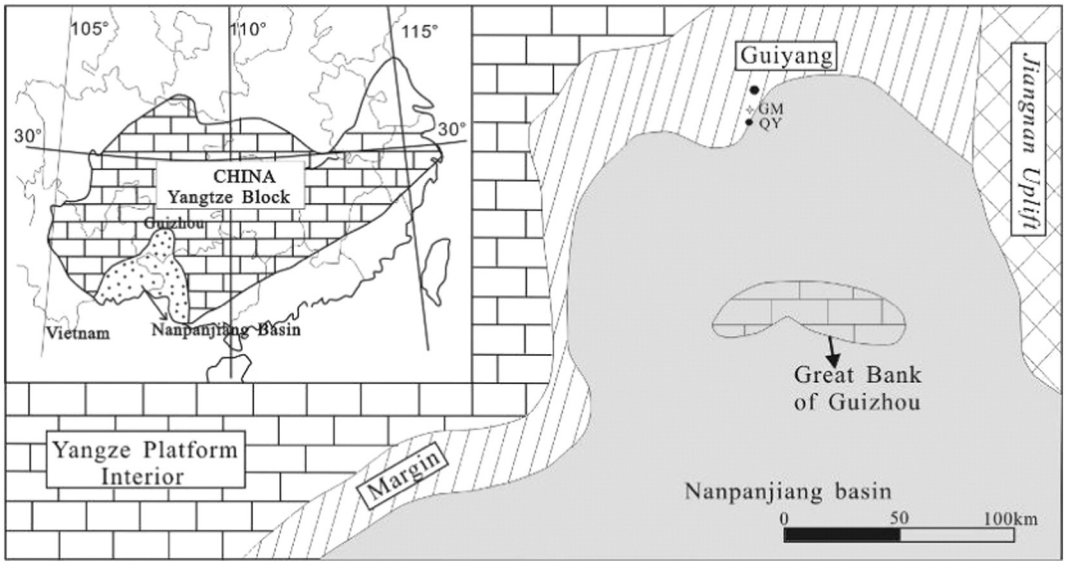


**Fig. 1.** Early Triassic paleogeographic map of the Nanpanjiang Basin (modified from Lehrmann et al., 2003). Inset is a tectonic map of South China modified from Sun et al. (1989), GM-Gaimao section, QY-Qingyan.