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# Complete biotic and sedimentary records of the Permian–Triassic transition from Meishan section, South China: Ecologically assessing mass extinction and its aftermath

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ABSTRACT

The Meishan section, South China is the Global Stratotype Section and Point (GSSP) for the Permian–Triassic boundary (PTB), and is also well known for the best record demonstrating the Permian–Triassic mass extinction (PTME) all over the world. This section has also been studied using multidisciplinary approaches to reveal the possible causes for the greatest Phanerozoic biocrisis of life on Earth; many important scenarios interpreting the great dying have been proposed on the basis of data from Meishan. Nevertheless, debates on biotic extinction patterns and possible killers still continue. This paper reviews all fossil and sedimentary records from the Permo-Triassic (P–Tr) transition, based on previously published data and our newly obtained data from Meishan, and assesses ecologically the PTME and its aftermath to determine the biotic response to climatic and environmental extremes associated with the biocrisis. Eight updated conodont zones: *Clarkina yini*, *Clarkina meishanensis*, *Hindeodus changxingensis*, *Clarkina taylorae*, *Hindeodus parvus*, *Isarcicella staeschei*, *Isarcicella isarcica*, and *Clarkina planata* zones are proposed for the PTB beds at Meishan. Major turnover in fossil fragment contents and ichnodiversity occurs across the boundary between Bed 24e-5 and Bed 24e-6, suggesting an extinction horizon in a thin stratigraphic interval. The irregular surface in the middle of Bed 27 is re-interpreted as a firmground of *Glossifungites* ichnofacies rather than the previously proposed submarine dissolution surface or hardground surface. Both fossil fragment contents and ichnodiversity underwent dramatic declines in Beds 25–26a, coinciding with metazoan mass extinction. Fossil fragment content, ichnodiversity and all ichnofabric proxies (including burrow size, tiering level, bioturbation level) indicate that the P–Tr ecologic crisis comprises two discrete stages, coinciding with the first and second phases of the PTME in Meishan. Ecologic crisis lagged behind biodiversity decline during the PTME. Pyrite framboid size variations suggest that depositional redox condition was anoxic to euxinic in the latest Changhsingian, became euxinic in Beds 25–26a, turned dysoxic in Bed 27, then varied from euxinic to anoxic through most of the Griesbachian. The ~9 °C increase in seawater surface temperature from Bed 24e to Bed 27 at Meishan seems to result in dramatic declines in biodiversity and fossil fragment contents in Beds 25–26a, but had little effect on all ecologic proxies. Both metazoans and infauna seem not to have been affected by the pre-extinction anoxic–euxinic condition. The anoxic event associated with the PTME may have occurred in a much shorter period than previously thought and is only recorded in Beds 25–26a at Meishan. Fossil fragment contents, ichnofaunas, ichnofabrics and pyrite framboid size all show that no signs of oceanic acidification and anoxia existed in Bed 27. The early Griesbachian anoxia may have resulted in rarity of ichnofauna and metazoans in the lower Yinkeng Formation, in which the ichnofauna is characterized by small, simple horizontal burrows of *Planolites*, and metazoan faunas are characterized by low diversity, high abundance, opportunist-dominated communities. The rapid increase of ~9 °C in sea-surface temperature and a short anoxia or acidification coincided with the first-pulse biocrisis, while a prolonged and widespread anoxia probably due to a long period of high seawater temperate condition may be crucial in mortality of most organisms in the second-pulse PTME. Marine ecosystems started to recover, coupled with environmental amelioration, in the late Griesbachian.



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**Contents**



## 1. Introduction

As the greatest biocrisis of life on Earth (Sepkoski, 1982), the Permian–Triassic mass extinction (PTME) changed Earth's ecosystems fundamentally (Benton and Twitchett, 2003; Erwin, 2006). After they had recovered, the marine ecosystems after the PTME gave rise to the forerunners of modern-day ecosystems, both the Triassic and modern ecosystems being comparable to each other in composition of functioning groups and trophic structure (Chen and Benton, 2012). However, the causes of this enigmatic biocrisis have long been disputed despite intense study, and the same is true of the profoundly delayed recovery following the PTME (Erwin, 2001). Thus, studies of these issues have enjoyed a surge in scientific interest in the past 30 years that shows no sign of abating (Chen et al., 2014).

Although this era-boundary crisis has been widely recognized in Permian–Triassic boundary (PTB) sections around the world, many important hypotheses have been proposed based on paleontological and experimental data sampled from the Meishan section of Changhsing County, Zhejiang Province, east China (Renne et al., 1995; Bowring et al., 1998; Jin et al., 2000; Kaiho et al., 2001; Mundil et al., 2001; Yin et al., 2001; Mundil et al., 2004; Grice et al., 2005; Xie et al., 2005; Kaiho et al., 2006a,b; Riccardi et al., 2006; Wang and Visscher, 2007; Xie et al., 2007; Cao et al., 2009; Chen et al., 2009; Song et al., 2009; Z.Q. Chen et al., 2010; Huang et al., 2011; S.Z. Shen et al., 2011; Yin et al., 2012; H.J. Song et al., 2013; H.Y. Song et al., 2013; Wu et al., 2013; Burgess et al., 2014; Wang et al., 2014; Fig. 1A). This section is the Global Stratotype Section and Point (GSSP) for the PTB (Yin et al., 2001; Fig. 1C) and also well known for the best record of both biotic and geochemical signals demonstrating the PTME all over the world. Here, the exposures of the PTB beds are spectacular, extending about 2 km laterally along the Meishan hill (Fig. 1E). The PTME has been well demonstrated by Jin et al. (2000), whose study based on paleontological data from Meishan reveals that this extinction event was abrupt and dramatic, with most Permian organisms being wiped out within a very short interval, which was precisely calibrated to the base of Bed 25, a white clay bed, in Meishan (Fig. 1B, D), while the PTB is placed at the middle of Bed 27, about 16–20 cm above the base of Bed 25 in the same section (Yin et al., 2001; Fig. 1C). As such, the biocrisis clearly pre-dated the PTB (Fig. 1D). The P–Tr ecologic crisis is also marked by a pronounced negative carbon isotopic excursion (Xu and Yan, 1993; Jin et al., 2000; Kaiho et al., 2001; Cao et al., 2002; Xie et al., 2005, 2007; Fig. 2) and is also associated with an end-Permian sulfur event (Kaiho et al., 2006a,b; Riccardi et al., 2006).

After Jin et al.'s (2000) influential study, which was largely based on fossil data obtained in the 1980s (i.e., Zhao et al., 1981; Liao, 1984; Sheng et al., 1984; Sheng et al., 1987; Shi and Chen, 1987), abundant brachiopod and foraminifer faunas have been detected from Beds 25 to 27, immediately above the PTME horizon in Meishan (Chen et al.,