Meishan Sections in South China: The Witness of the Largest Biological Mass Extinction during the Phanerozoic

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Abstract

Spectacular Permian–Triassic sequences are exposed in a series of quarries at Meishan, Zhejiang Province in Southeast China. The Meishan sections have become the most intensively-studied sections to unravel the patterns and causes of the end-Permian mass extinction. Section D is the unique section with two Global Stratotype Section and Points (GSSPs) formally ratified by International Union of Geosciences. The Meishan Geopark is established.

Key words : Meishan sections, end-Permian, mass extinction, GSSP

I. Introduction

It has been well documented that the Phanerozoic experienced five big biological mass extinctions (Big Fives). Among them, the extinction happened at the end of Permian is the biggest (Sepkoski, 1981; Raup and Sepkoski, 1982; Erwin, 2006). About 95% of marine organisms were wiped out by an environmental catastrophe of a magnitude never seen before or since, and approximately 75% of animals and plants on land suffered similarly. Recovery of marine ecosystems following the end-Permian mass extinction was about 5 million years (mys) long and progressed very slowly until Middle Triassic (Payne *et al.*, 2004; Lehrmann *et al.*, 2006). Possible causes of the end-Permian mass extinction include an extremely fast, explosive release of methane or other gases such as carbon dioxide and hydrogen sulfide (Krull and Retallack, 2000; Ryskin, 2003; Shen S.Z. *et al.*, 2011), increased volcanism (Campbell *et al.*, 1992; Renne *et al.*, 1995), coal/gas fires and

Fig. 1 Locality index map of the Meishan sections.

explosions from the Siberian Traps (Ryskin, 2003; Shen S.Z. *et al.*, 2011; Darcy and Norman, 2012), multiple bolide impact events (Kaiho *et al.*, 2001; Becker *et al.*, 2004), oceanic anoxia (Wignall and Twitchett, 1996; Isozaki, 1997) and a shift in ocean circulation driven by climate change or a combination thereof (Erwin, 1994) etc. Recent extensive studies show that the Permian–Triassic boundary (PTB) sequences from shallow marine, slope to intra-platform basin are well developed in South China. These sequences recorded the

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Fig. 2 A: geological map of the Meishan area in Zhejiang Province, China; B: a distal view of the series of sections from A to E, Z at Meishan.

whole process of the greatest dying and thereafter recovery in the earth history. Among them, the Permian-Triassic (P-Tr) sequence at the landmark Meishan sections (Figs. 1-2) has been visited by numerous worldwide scientists since it was discovered in the 1930s. They have become the most intensively-studied sections on the end-Permian mass extinction in the world.

II. Geological setting and stratigraphy

Meishan is a small town and about 20 km to the Changxing County, Zhejiang Province in

southeastern China (Fig. 2A). The Meishan sections (Section D: 31°4'50.38"N; 119°42'21.68"E) are about 2 km from the Meishan Town and have been well protected. The P-Tr lithological succession is very well exposed in a series of quarries from A to E and Z from west to east near the Meishan Town (Fig. 2B) which were excavated to use the limestone of the Changhsing Formation for construction. The type section for the Changhsing Limestone is located at Section D.

In Meishan, the Lopingian (Late Permian) Lungtan Formation is characterized by a coal-

Fig. 3 Stratigraphical column with high-resolution conodont zones, geochronologic ages and both $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ from the Meishan sections (Data from Cao *et al.*, 2009; Shen S.Z. *et al.*, 2011).

bearing measure with highly diverse *Gigantopteris* flora and abundant marine fossils. Only the topmost part of this formation is exposed at the Meishan sections. This formation is of Wuchiapingian age. The Changhsing Formation is mainly composed of medium- to thick-bedded limestone containing highly diverse marine fossils including tens of different fossil groups such as conodonts, ammonoids, fishes, brachiopods, fusulinids, radiolarians and foraminifers, and dominated by slope facies deposits. This formation is about 46 m thick and contains abundant volcanic ash beds. The overlying Yinkeng Formation from the uppermost Changhsingian to the Lower Triassic is marked by a distinct ash bed (Bed 25) just below the PTB at the sections. It comprises two members; the lower member dominated by thin-bedded micritic limestone with intercalations of shale and a few ash beds containing numerous disaster bivalve species, and the upper member, 170 m thick, consists of medium- to thick-bedded micritic limestone.

III. High-resolution integrative time framework and two GSSPs

As a consequence of intensive studies of various aspects of stratigraphy, a high-resolution biostratigraphical framework based on conodonts and other fossils from the base of the sections (Wuchiapingian) to the Lower Triassic were established (Zhao *et al.*, 1981; Mei *et al.*, 1998; Yin *et al.*, 2001; Zhang *et al.*, 2007). The topmost part of the Lungtan Formation and the basal part of the Changhsing Formation is marked by the abundant occurrences of the conodont *Clarkina orientalis* and *C. longicuspadata* (Mei *et al.*, 2004; Jin *et al.*, 2006). Five conodont zones are recognized from the Changhsingian at the Meishan sections. They are the *Clarkina wangi*, *C. subcarinata*, *C. changxingensis*, *C. yini*, *C. meishanensis*-*Hindeodus praeparvus* zones in ascending order (Mei *et al.*, 1998; Jiang *et al.*, 2007; Zhang *et al.*, 2007; Shen and Mei, 2010) (Fig. 3). The PTB is located in the middle part of a limestone bed (Bed 27) with a hardground, which may indicate short hiatus (Cao and Shang, 1998). The high-resolution integrated biostratigraphical

successions for the Changhsingian Stage and the P-Tr transition at the Meishan sections have led to the ratifications of two Global Stratotype Section and Points (GSSPs) at the Meishan Section D by IUGS (Yin *et al.*, 2001; Jin *et al.*, 2006). Thus, the Meishan Section D has become the unique section with two GSSPs and a unit stratotype of the Changhsingian Stage is defined there (Fig. 4).

In addition to the detailed studies of biostratigraphy, the Meishan sections also contain volcanic ash beds and carbonized tuffs at about 35 different levels. Intensive dating based on uranium/lead ratios of zircons from the ash beds at the Meishan sections have been carried out by different international laboratories (Renne *et al.*, 1995; Bowring *et al.*, 1998; Mundil *et al.*, 2004). Latest results using U-Pb isotope dilution thermal ionization mass spectrometry (ID-TIMS) have established a high-precision time framework of the Meishan sections. Seven ash beds from ~ 40 m of section were dated. Bed 6 (4.9 m above the base of the Changhsingian Stage) is 253.49 ± 0.07 Ma. Bed 7 is 253.45 ± 0.08 Ma. Bed 15 in the middle part of the Changhsingian yielded a date of 252.85 ± 0.11 Ma. Bed 22 (~ 4.5 m below the PTB) is 252.50 ± 0.11 Ma. Bed 25 is 252.28 ± 0.08 Ma. Bed 28 is 252.10 ± 0.06 Ma (Fig. 3) (Shen S.Z. *et al.*, 2011). The PTB is calculated by interpolation to be 252.17 ± 0.06 Ma and the Wuchiapingian/Changhsingian boundary is calculated by interpolation to be 254.14 Ma based on the ages of ash beds relative to the first occurrence of *Clarkina wangi* at the Shangsi and Meishan sections (Fig. 3).

IV. The end-Permian catastrophic extinction

Numerous critical results of palaeontological, geochronologic and geochemical data for the end-Permian mass extinction have been reported from the Meishan sections. A statistic analysis of 15 marine fossil groups systematically collected from five sections at Meishan shows a catastrophic extinction happened at Bed 25 and experienced no more than half mys (Jin *et al.*, 2000) (Fig. 5). Latest dating of the ash beds around the P-Tr

Fig. 4 The two Global Stratotype Section and Points (GSSPs) at the Meishan Section D showing the Permian-Triassic boundary (A) and Wuchiapingian-Changhsingian boundary (B). C: A photo showing the GSSP square of the Meishan Geopark with a monument approximately pointing the Permian-Triassic boundary in a distal quarry (Section C).

Fig. 5 The extinction pattern of the Meishan sections (after Jin *et al.*, 2000).

transition at Meishan suggest that the main extinction event began in Bed 24e just before 252.28 ± 0.08 Ma (age of Bed 25) and lasted no longer than 200 ± 100 Kyr (from Bed 24e to Bed 28) (Fig. 3B). This extinction has been confirmed in a large geographic area both in the sea and on land based on statistic palaeontological data from tens of different marine and terrestrial sections in South China and Tibet (Shen S.Z. *et al.*, 2011). On the other hand, some researchers have suggested multiple pulses of the extinction in various levels in the P-Tr transition (Feng *et al.*, 2007; Yin *et al.*, 2007; Song *et al.*, 2009) and others suggested that the environmental deterioration resulted in the end-Permian mass extinction probably began from the Late Guadalupian (Middle Permian) associated with the breakup of the supercontinent Pangea, about 8 mys before the last catastrophe at the end of the Changhsingian (Isozaki *et al.*, 2007; Yin *et al.*, 2007; Isozaki, 2009).

Associated with the biological extinction, various geochemical studies suggest dramatic environmental changes around the extinction. A large, abrupt global negative shift of both

$\delta^{13}\text{C}_{\text{carb}}$ and $\delta^{13}\text{C}_{\text{org}}$ coincides with this extinction (Fig. 3). At the Meishan sections, a progressive negative downturn in C isotopic composition of 2.4‰ over 1.79 m preceded the sudden drop was detected. This downturn is followed by a sharp 5‰ negative $\delta^{13}\text{C}$ isotopic anomaly over 5 cm that starts abruptly within the topmost part of Bed 24e and ends in Bed 25 (Cao *et al.*, 2002, 2009; Xie *et al.*, 2007) and had a duration less than 20 ± 10 Kyr (Shen S.Z. *et al.*, 2011) (Fig. 3B). Biomarkers and sulfur isotopes from the Meishan sections indicate that anoxic or euxinic conditions and microbial expansion prevailed the extinction interval (Grice *et al.*, 2005; Xie *et al.*, 2005; Cao *et al.*, 2009; Shen Y. *et al.*, 2011). Recent study based on oxygen isotope ratios measured on phosphate-bound oxygen in conodont apatite from the Meishan sections indicates that a very rapid climatic warming (an 8°C rise in temperature) is consistent with the extinction (Joachimski *et al.*, 2012). Thus, an extremely fast, explosive release of methane and/or coal/gas fires and explosions triggered by Siberia flood volcanism becomes one of the most popular scenarios for the end-Permian mass extinction (Ryskin, 2003; Shen S.Z.

et al., 2011; Darcy and Norman, 2012; Payne and Clapham, 2012).

V. The Meishan Geopark

The Meishan sections, the most intensively-studied section in the world with the unique Changhsingian body stratotype constained by two GSSPs (Fig. 4), recorded the whole process of the end-Permian mass extinction. It has become the base for popular science for understanding the earth history. A geopark and an exceptional palaeontological museum were established there. The Meishan Geopark creates a rich storehouse to be explored for the P-Tr world, the GSSPs, volcanic ashes, the history of the largest mass extinction happened during the Phanerozoic and the local culture. The Meishan Museum exhibits a graphic illustration of the life history on the earth, various fossils, minerals and distinguished Chinese scientists who studied the Meishan sections. It has become the most popular site to visit for students in Southeast China and provides support to communicate geoscientific knowledge and environmental concepts to the public. It also fosters scientific research and cooperation with scientists all over the world.

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南中国，煤山セクション

— 顕生代最大の大量絶滅の記録 —

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中国南東部，浙江省の煤山採石場^{めいしやん}には一連の古生代ペルム紀／中生代三疊紀の見事な連続層が露出している。この地層断面はペルム紀末の大量絶滅のパターンと原因を解明するため世界で最も詳しく研究されてきた。多産する化石の層序に加えて，凝灰岩の正確な年代測定や炭素同位体比層序

が明らかにされている。中でも，国際地質科学連合で承認された2つの地層境界の世界模式標準層序セクション・地点を含むDセクションは，重要である。最近，煤山ジオパークがオープンした。

キーワード：煤山セクション，ペルム紀末，大量絶滅，世界模式標準層序セクション・地点

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