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Triggers of Permo-Triassic boundary mass extinction in South China: The Siberian Traps or Paleo-Tethys ignimbrite flare-up?

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ABSTRACT

Assessment of the synchroneity between the Siberian Traps and the Permo-Triassic boundary (PTB) mass extinction has led to the proposition that the Siberian flood volcanism was responsible for the severest biotic crisis in the Phanerozoic. However, recent studies suggest that the Siberian Traps may have postdated the main extinction horizon. In this paper, we demonstrate, using stratigraphy, a time and intensity coincidence between PTB volcanic ash and the main extinction horizon. Geochemistry of the PTB volcanic ashes in five sections in South China indicates that they were derived from continental magmatic arc. Zircons extracted from the PTB volcanic ashes have negative $\varepsilon_{Hf(t)}$ (-12.9 to -2.0) and $\delta^{18}O$ (6.8 to 10.9‰), consistent with an acidic volcanism and a crustal-derived origin, and therefore exclude a genetic link between the PTB mass extinction and the Siberian Traps. On the basis of spatial variation in the number of the PTB volcanic ash layers and the thickness of the ash layers in South China, we propose that the PTB volcanic ash may be related to Paleo-Tethys continental arc magmatism in the Kunlun area. Ignimbrite flare-up related to rapid plate subduction during the final assemblage of the Pangea super-continent may have generated a volcanic winter, which eventually triggered the collapse of ecosystem and ultimately mass extinction at the end of the Permian. The Siberian Traps may have been responsible for a greenhouse effect and so have been responsible for both a second pulse of the extinction event and Early Triassic ecological evolution.

1. Introduction

The Permo-Triassic boundary (PTB) mass extinction was the severest biotic crisis in Phanerozoic, affecting over 90% marine species, 70% land vertebrate genera and most land vegetation (Erwin, 1994). Although no consensus has been reached so far on the causal mechanisms, the ~250 Ma Siberian Traps is widely believed to be the ultimate cause of PTB mass extinction due to the coincidence of these two events (e.g., Campbell et al., 1992; Courtillot, 1994; Courtillot and Renne, 2003; Kamo et al., 2003, 2006; Racki and Wignall, 2005; Reichow et al., 2002; Renne et al., 1995). However, two potential pitfalls are associated with this methodology/reasoning:

(a) If the two events took place at the same time, they are possibly but not necessarily related to each other. In the PTB case, the role of volcanism as the cause of mass extinction is considered important given the presence of numerous volcanic ash layers around the PTB. If this volcanic ash has the same age and composition as those of the Siberian Traps, a consanguineous association between them can thus be established. The PTB volcanic ash was previously considered to be felsic rather than mafic and be related to plate subduction or a magmatic arc (e.g., Clark et al., 1986; Yang et al., 1991; Yin et al., 1992, 2007; Zhou and Kyte, 1988). Thus, the provenance of the PTB volcanic ash and its genetic relationship related to the Siberian Traps deserve further investigation.

(b) The link between the Siberian Traps and the PTB mass extinction was initially established based on the synchroneity of these two events. However, the dating techniques used in the early studies on PTB (SHRIMP and Ar–Ar dating) generally have the analytical precision of ~1%, which corresponds to an uncertainty of 2–3 Ma (Campbell et al., 1992; Renne et al., 1995). Such an uncertainty is insufficient to constrain the temporal relationship of the PTB and the mass extinction which is believed to have occurred within 0.2 Myr (Shen et al., 2011). A newly developed zircon U–Pb dating technique, chemical abrasion-thermal ionization mass spectrometry (CA-TIMS), can improve the precision up to 0.1% on the analyses for individual zircon grains, and is therefore suitable for the accurate age constraints of PTB (Shen et al., 2011). The CA-TIMS zircon U–Pb ages for the Siberian Traps indicate that the eruption of the flood basalts mainly occurred between 251.7 ± 0.4 and 251.3 ± 0.3 Ma (Kamo et al., 2003), which significantly postdate the main PTB extinction horizon (252.28 ± 0.08 Ma)

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(Shen et al., 2011) (Fig. 1). This result is consistent with the observation that the transition from Permian to Triassic fossil assemblages in Russia had started before the eruption of the Siberian Traps (Sadovnikov, 2008). Therefore, the model involving the Siberian Traps as the most significant cause of the PTB mass extinction needs to be re-evaluated.

In this study, we carried out an integrated investigation of geology, mineralogy, whole-rock geochemistry and zircon Hf–O isotopes of the PTB volcanic ash in South China, in order to define the relationship between the volcanic ash and the PTB mass extinction, and to unravel the provenance of volcanic ashes around the PTB. Our results show that (1) the main PTB extinction horizon rests on a layer of volcanic ash, consistent with a causal link between the volcanism and mass extinction, and (2) a crustal origin of the PTB volcanic ash layers, which rules out a genetic link to the Siberian Traps. Finally, we propose that the PTB volcanic ash in South China may be related to ignimbrite flare-up caused by rapid plate subduction during Pangea assembly.

2. Geological background and sampling

The Permian–Triassic boundary Global Stratotype Section and Point (GSSP) was established at D section of Meishan, Changxing, Zhejiang Province in South China (Yin et al., 2001). The well-established stratigraphic columns of a number of the PTB sections in South China show that abundant volcanic ash occurs around PTB (Fig. 2). These ash layers have been extensively studied in the past 30 years (e.g., Bowring et al., 1998; Clark et al., 1986; Metcalfe et al., 1999; Mundil et al., 2001, 2004; Shen et al., 2011, 2012, 2013; Zhou and Kyte, 1988). It is widely accepted that the PTB volcanic ash layers may have been deposited during the latest Permian and the earliest Triassic, and that they are felsic in composition and may have been formed in a subduction-related setting (Clark et al., 1986; Gao et al., 2013; Isozaki et al., 2007; Shen et al., 2012; Yang et al., 2012; Yin et al., 2007; Zhou and Kyte, 1988).

Five typical PTB sections (Meishan, Shangsi, Chaotian, Dongpan and Rencunping) in South China (Fig. 3) are targeted in this study for mineral and whole-rock compositions and zircon Hf–O isotopic analyses. Using our own field observations with those reported in the literature, the main characteristics of the PTB volcanic ash layers in South China are summarized as follows:

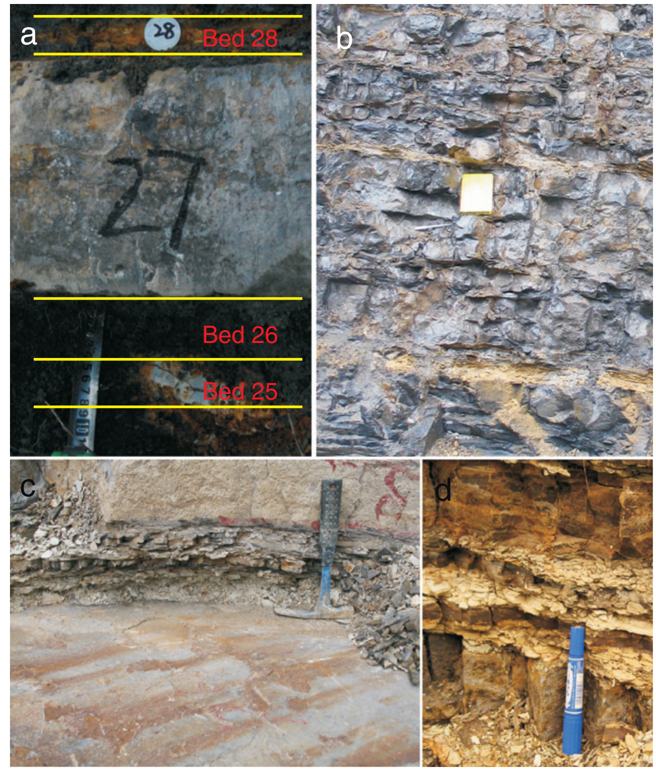

Fig. 2. Field photographs of the PTB volcanic ashes at (a) Meishan, (b) Chaotian, (c) Shangsi, and (d) Dongpan sections. Note: The length of the yellow notebook in (b) is 18 cm.

(1) Although the presence of abundant volcanic ash is common in all the PTB sections in South China, the numbers of ash layers and

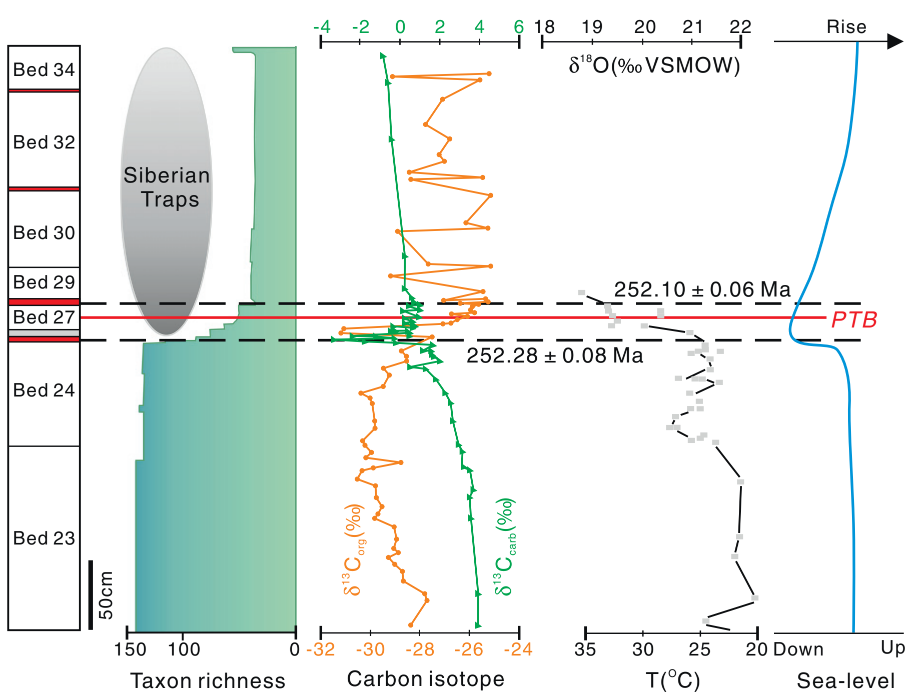

Fig. 1. A chart showing the PTB event sequences at Meishan section. Data sources: Bed numbers are after Yin et al. (2001); age, bio-diversity, $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ are after Shen et al. (2011); $\delta^{18}O$ of conodonts and inferred sea-water surface temperature are after Joachimski et al. (2012); and duration of Siberian Traps is after Kamo et al. (2003). PTB = Permo-Triassic boundary.