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A conodont-based revision of the $^{87}Sr/^{86}Sr$ seawater curve across the Permian-Triassic boundary

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ABSTRACT

Based on analyses of 565 conodonts from Meishan, Liangfengya, and Daijiagou (South China), and Abadeh (central Iran), we propose a revision of the seawater $^{87}Sr/^{86}Sr$ curve for the time period spanning 200 kyr prior to the Permian-Triassic boundary (PTB) to 330 kyr after the PTB. With carefully designed sample cleaning, conodonts faithfully record seawater $^{87}Sr/^{86}Sr$. Seawater $^{87}Sr/^{86}Sr$ was 0.707030 ± 10,200 kyr prior to the PTB, rose to 0.707070 ± 10 approximately 39 kyr prior to the PTB (at the marine extinction horizon, the top of Bed 24e at Meishan), to 0.707080 ± 10 at the PTB, and to 0.707120 ± 20 at 330 kyr after the PTB. The rate of change of seawater $^{87}Sr/^{86}Sr$ was 0.0000185/Myr from the Capitanian minimum to ~100 kyr before the PTB, and was 0.00020 ± 7.5/Myr between ~100 kyr before and 330 kyr after the PTB. Over 6 Myr, this rate of change would result in a maximum $^{87}Sr/^{86}Sr$ of ~0.70825 at the end of the Early Triassic, compared with a model value of ~0.7080. The Sr data are consistent with the interpretation that the rise in marine $^{87}Sr/^{86}Sr$ was due primarily to an increase in the continental weathering and erosional flux, and that soil-binding vegetation was not re-established during most of the Early Triassic. The rapid rise in seawater $^{87}Sr/^{86}Sr$ began at least 30 kyr prior to the marine extinction at Meishan, indicating that the terrestrial extinction preceded that in the oceans.

1. Introduction

The rapid rise of marine $^{87}Sr/^{86}Sr$ across the Permian-Triassic boundary (PTB) has long been known (Peterman et al., 1970; Veizer and Compston, 1974). The approximate magnitude of that rise, from about 0.7068 at the Capitanian minimum (~260 Ma) to nearly 0.7080 at the end of the Early Triassic (~245 Ma) has also been known (Martin and Macdougall, 1995; McArthur et al., 2001; Veizer et al., 1999), providing a rough estimate of the rate of change of oceanic $^{87}Sr/^{86}Sr$ during this pivotal period in the history of life on Earth. This contribution attempts to refine what we know about marine $^{87}Sr/^{86}Sr$ in a 0.5-Myr interval straddling the PTB, so that we can constrain both the timing of that change with respect to the end-Permian extinction event, and its magnitude. We do not attempt to model the marine $^{87}Sr/^{86}Sr$ system: that is a task for others who have studied the magnitude and composition of the weathering and mid-ocean ridge Sr fluxes (Allégre et al., 2010; DePaolo, 1980; Palmer and Edmond, 1989; Pearce et al., 2015; Richter and Turekian, 1993; Song et al., 2015).

The new data we present are primarily from conodonts, taken from 5 different PTB sections in China and Iran, including the GSSP (Global Stratotype Section and Point) for the PTB at Meishan, China (Fig. 1). Our data differ from the best current model of marine $^{87}Sr/^{86}Sr$ over this time period, the LOWESS curve (Fig. 2) of McArthur et al. (2012). Between 254 and 248 Ma, the LOWESS curve relies on approximately 30 well-characterized data points derived from other studies. The LOWESS data are primarily from brachiopods and conodonts because other matrices - whole rock carbonates (Denison et al., 1994) and sulfates (Denison and Peryt, 2009), other fossils (Brand, 2004), and many conodonts - are less robust in retaining primary marine compositions. For the PTB interval, data from low-Mg calcite in brachiopods are likely to reflect marine $^{87}Sr/^{86}Sr$ most reliably (Brand et al., 2012), and can be treated as a standard against which the fidelity of conodont data can be assessed. McArthur et al. (2012) screened data based on the precision of the analyses, the accuracy of the data reported from each laboratory, and the precision with which samples were located in space and time, so that each sample could be linked to an internally consistent temporal scale.

The age assignments for our data are based on U/Pb zircon dating of ash beds in the Meishan section. Though there are many age data for Meishan, we have chosen the Burgess et al. (2014) data because they have the smallest analytical uncertainties, are internally consistent (all analyses were completed in a single laboratory with a uniform protocol; Bowring et al., 2011; Condon et al., 2015; McLean et al., 2011), and include five ash beds that bracket the PTB and the extinction interval. These ages require the fewest ancillary assumptions. An

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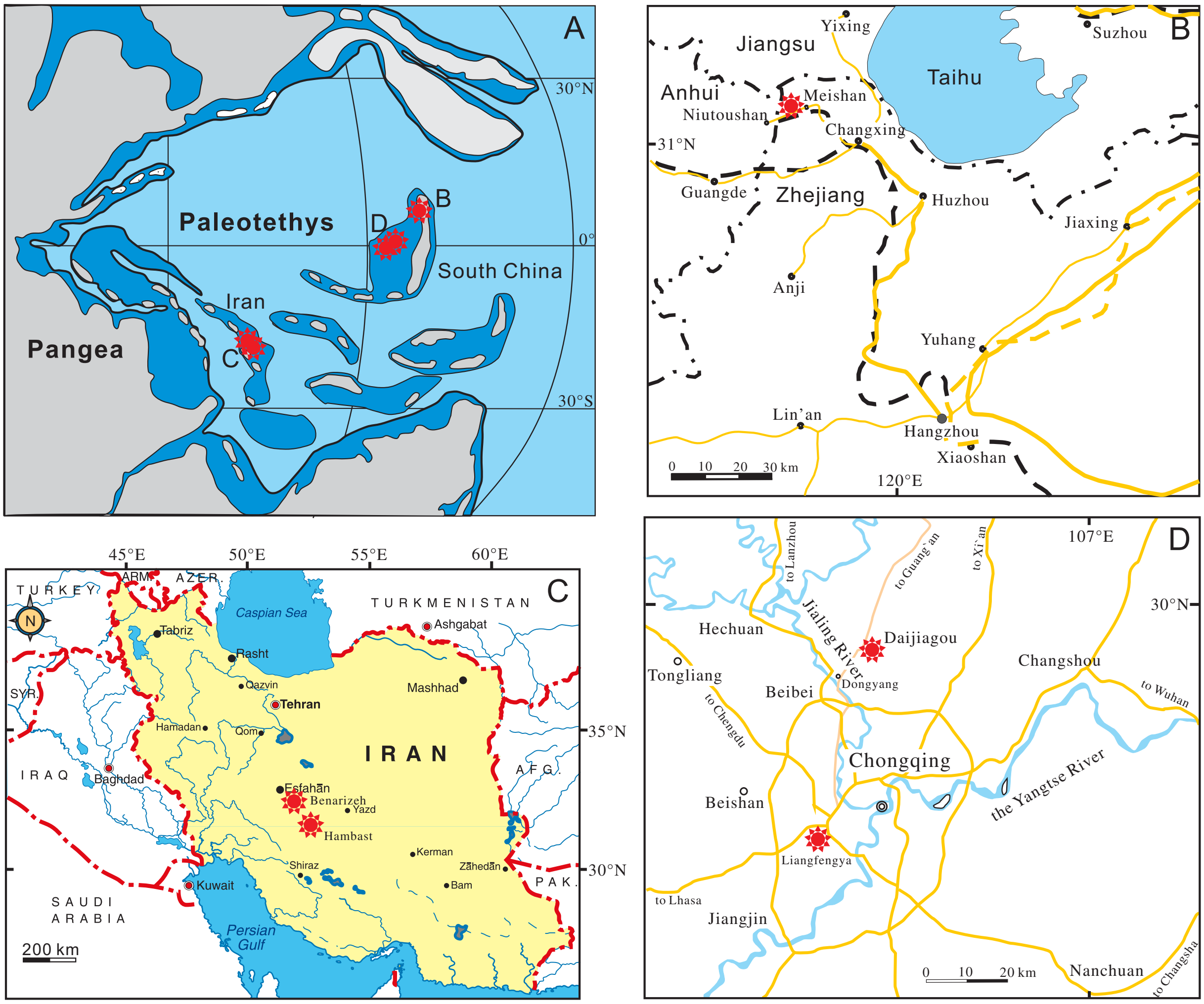

Fig. 1. A paleogeographic reconstruction (Ziegler et al., 1997; Shen S.Z. et al., 2013) showing the marine shelf of the Paleotethys Ocean, and the locations of the five studied sections.

astronomically-tuned time-scale (Li et al., 2016) for Meishan differs in detail but is anchored by the U/Pb measurements of Burgess et al. (2014). These U/Pb dates at Meishan provide a time-scale for conodont biostratigraphy, and biostratigraphy provides temporal constraints in sections where there are no U/Pb dates.

There is a clear increase of terrestrial weathering and erosion near the PTB (Sephton et al., 2005) due to devegetation on land (Algeo et al., 2011; Erwin, 1993; Kozur and Weems, 2011; Retallack, 1995; Song et al., 2015). If the weathered and eroded materials had the $^{87}Sr/^{86}Sr$ of average continental sediments (∼ 0.712; Pearce et al., 2015; Peucker-Ehrenbrink et al., 2010), the increase of marine $^{87}Sr/^{86}Sr$ most likely reflects this increased sediment input. Thus, the timing of the change in marine $^{87}Sr/^{86}Sr$ potentially allows us to determine whether the terrestrial and marine extinctions were contemporaneous.

The mixing time of the oceans with respect to Sr is short (<10 kyr; Broecker and Peng, 1982) compared to the Sr residence time (∼2.5 Myr; Broecker and Peng, 1982; Palmer and Edmond, 1989; Pearce et al., 2015). This means that the oceans are homogeneous with respect to $^{87}Sr/^{86}Sr$, and that changes in marine $^{87}Sr/^{86}Sr$ occur slowly: input and output fluxes are small compared with the size of the marine Sr reservoir. The slow increase of $^{87}Sr/^{86}Sr$ from the Capitanian minimum into the Late Permian (McArthur et al., 2012) reflects a system that is close to steady-state. The timing of the perturbation of that system, leading to a rapid rise of marine $^{87}Sr/^{86}Sr$ in the Early Triassic, is not well-constrained, and this study attempts to improve that chronological constraint.

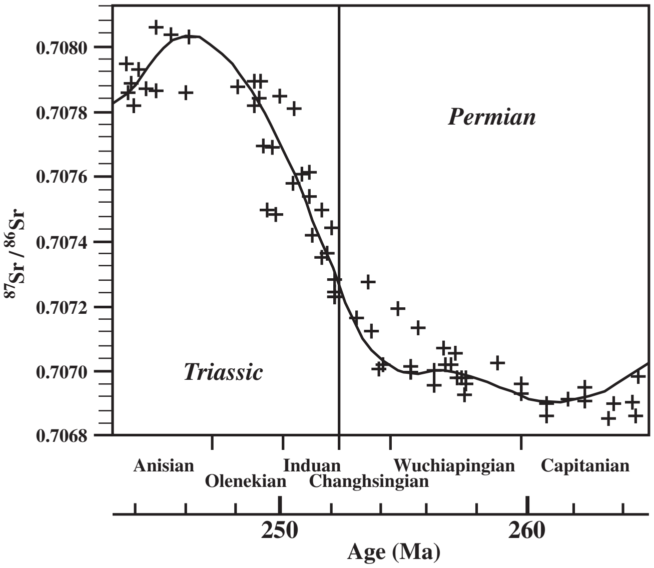

Fig. 2. The LOWESS (McArthur et al., 2012; preliminary V5; PTB = 252.2 Ma) seawater $^{87}Sr/^{86}Sr$ curve for the period 265–243 Ma. Data points are from the literature, selected by McArthur et al.