Forum Reply

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Did the great dying of life take 700 k.y.? Evidence from global astronomical correlation of the Permian-Triassic boundary interval

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We thank Rampino and Kaiho (2012) for their Comment on our Geology paper (Huang et al., 2011). They questioned our definition of a mass extinction interval (MEI) for the Permian-Triassic (P-Tr) boundary interval. We define the MEI as the stratigraphic interval from the start of the *Neogondolella meishanensis* conodont zone, or its equivalents at the onset of the negative $\delta^{13}C$ excursion (ME_{start}), to the base of the *Isarcicella isarcica* conodont zone and increasing $\delta^{13}C$ values (ME_{end}).

At the Meishan (China) section, the *N. meishanensis* zone starts at the base of Bed 25, which is widely accepted as the main mass extinction horizon. Thus, we treat this horizon as ME_{start}. Kaiho et al. (2009) proposed the main mass extinction to be within an interval of 1.2 cm near the top of Bed 24e based on examination of continuously sampled microfossils. However, quantitative analysis, e.g., evaluation of the Signor-Lipps effect, shows that the main mass extinction falls at the top of Bed 24e or the base of Bed 25 (Jin et al., 2000; Song et al., 2009; Shen et al., 2011). The *I. isarcica* zone starts at the base of Bed 29 (Jiang et al., 2007). An extinction horizon was recognized in the base of Bed 28 (Yin et al., 2007; Song et al., 2009). However, Bed 28 is a volcanic ash bed, representing a very short duration, and is not preserved in P-Tr boundary sections worldwide. To enable recognition of this extinction horizon and its equivalent in other sections, we used the base of the *I. isarcica* zone as a marker of ME_{end}. We also considered MEI durations based on both options (GSA Data Repository item 2011231). Also, the "cycles" in our eccentricity count at Meishan included Beds 25 and 28, which are not true cycles, but ash beds—hence likely "instantaneous" events.

For the Gartnerkofel core (Austria) discussed by Rampino and Kaiho, we considered two definitions of the MEI (Huang et al., 2011). Biostratigraphic correlation places ME_{start} at 231 m (base of the *Hindeodus latidentatus* zone) and ME_{end} at 188.6 m (base of *I. isarcica*) for a MEI thickness of 42.4 m (Schönlaub, 1991). Alternatively, $\delta^{13}C$ profile correlation places ME_{start} at 224.97 m and ME_{end} at 182 m. Either scheme gives the same duration.

Our definition of an MEI focuses not only on the main mass extinction event in the Late Permian, but also considers the immediate aftermath and the succeeding extinctions through the P-Tr boundary. Rampino and Kaiho consider only the Late Permian mass extinction event, which we have termed here as the main mass extinction. Recent studies indicate that abundant Permian fossils occur above the main extinction event horizon (Chen et al., 2005; Song et al., 2009; Korchagin, 2011), and most finally disappear at Bed 28. The most distinctive change in benthic community structures did not occur in the main mass extinction event, but coincided with the later demise of the temporary survivors (Chen et al., 2010). Consequently, P-Tr biotic extinctions and ecosystem collapse are recorded in the MEI. We show that the MEI can be correlated worldwide with biostratigraphic and $\delta^{13}C$ profile correlations (Huang et al., 2011).

Permian fossils may occur only in an interval of 0.3 m to 1 m above the main mass extinction horizon in the Italian sections (Rampino and Kaiho, 2012). However, abundant Permian foraminifers extend up to the *I. staeschei* zone at Meishan (Song et al., 2009; Korchagin, 2011). If our MEI definition is considered, combined conodont biostratigraphy and $\delta^{13}C$ patterns suggest a much broader extinction interval than suggested by Rampino and Kaiho.

We therefore believe that the P-Tr mass extinctions may be accounted for by a series of critical events rather than a single catastrophe. We also note that an eccentricity minimum occurs ~200 k.y. prior to the onset of the MEI (Huang et al., 2011), which could have influenced or paced the impending extinctions. We favor a new campaign to measure cyclostratigraphy at high resolution across these and other biostratigraphically constrained sections worldwide to help solve the timing problems of the P-Tr mass extinctions.

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