

Cyanobacterial blooms tied to volcanism during the 5 m.y. Permo-Triassic biotic crisis

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We welcome the Comment from Reichow and Saunders (2011) and are glad that they agree with our main conclusion on the relationship among cyanobacterial blooms, volcanism, and carbon isotope excursions across the Permian–Triassic boundary (Xie et al., 2010). They do challenge, however, whether the existing chronology and the use of age data from different radiometric systems is sufficient to argue for or against a connection between the Siberian eruption and the prolongation of stressful conditions in the aftermath of the end-Permian mass extinction.

We agree that the robustly applicable correction among different dating methods is not established. A 1% difference is generally used for the correction between U/Pb and ⁴⁰Ar/³⁹Ar dating, but a 1.29% difference is observed in bed 28 ash in the Meishan section (eastern China). Even the ⁴⁰Ar/³⁹Ar age, after recalculation (251.7 ± 0.1 m.y.) (Reichow and Saunders, 2011) to the recommended Fish Canyon sanidine age of Renne et al. (2010), is not consistent with U/Pb dating (252.5 ± 0.3 m.y.) in bed 28. That is why we did not correct the ⁴⁰Ar/³⁹Ar data to U/Pb data but denoted the dating methods in our paper.

However, we did not mean to make an intercomparison between the two sets of data without any correction. Instead, we consider it necessary to intracompare dates derived from the same method. We showed the U/Pb dating data of both the Siberian basalt and strata boundary ages for comparison in our figure 2 (Xie et al., 2010). The only U/Pb dates derived from Siberian basalt range from 251.7 ± 0.4 to 251.3 ± 0.3 m.y. (Kamo et al., 2003) and were previously proposed to be synchronous with the previous U/Pb age (251.4 ± 0.7 m.y.) (Bowring et al., 1998), but postdate the new U/Pb age (252.4 ± 0.3 m.y.) (Mundil et al., 2004) for the end-Permian biotic crisis (i.e., the age of bed 25 ash in Meishan). Thus, the U/Pb dating of individual zircon grains from both Meishan ash and Siberian basalt provides the first line of evidence that at least some Siberian volcanism postdates the extinction. Significantly, the transition from Permian to Triassic fossil assemblages in the region was suggested to begin well before the basalt eruption (Sadovnikov, 2008) in the Nidymsky suite in Lower Tunguska River (Russia). The biostratigraphical constraints thus provide a second line of evidence.

We did include in our figure 2 the ⁴⁰Ar/³⁹Ar data associated with the only available U/Pb dating in Maymecha (Russia), but the purpose of this was not for comparison to U/Pb dates associated with Siberian volcanism or any other strata. Rather, it was included to allow intracomparison with ⁴⁰Ar/³⁹Ar data from other sites where U/Pb dating is absent (Xie et al., 2010). Because the U/Pb data from Maymecha suggest that extinction predates Siberian volcanism, and the associated ⁴⁰Ar/³⁹Ar data overlap the other ⁴⁰Ar/³⁹Ar data of Siberian basalt, the latter ⁴⁰Ar/³⁹Ar data should also

postdate the biotic event. We admit that the incorporation of the two sets of data in our figure 2 could cause a misunderstanding.

However, a precise intracomparison of the ⁴⁰Ar/³⁹Ar data between Siberian basalt and bed 25 ash in Meishan is not possible due to the large difference in errors (Reichow et al., 2009; Saunders and Reichow, 2009), with the error being only 0.15 m.y. for bed 25 ash but over 0.5 m.y. (most >1 m.y.) for Siberian basalt. Due to the large error of ⁴⁰Ar/³⁹Ar data, Siberian basalt could still overlap bed 25 ash in dating even if the latter was moved upward (younger) or downward (older) by 1 m.y. in figure 5 of Reichow et al. (2009). However, we do not find that comparison to be strong evidence for coincidence. In fact, few Siberian samples have mean values that overlap with the age of bed 25 ash. Furthermore, most of the data suggesting eruptions predate extinctions (Reichow et al., 2009, their figure 5) are questionable. For example, samples FGS-1, FGS-5, and FGS-8, much older than the bed 25 ash in Meishan, are not eruptive, but intrusive igneous rocks (gabbros) (Reichow et al., 2009). Also, sample SG32–54 taken from the top of the Norilsk basalt is surprisingly older than the bottom samples. Samples 322/1 and 322/4 in Vorkut, with a thickness interval of 3.5 m, differ in age by 2.3 m.y., which is striking given that the total thickness of basalt is thousands of meters.

Consequently, there is compelling, if not conclusive, evidence that significant Siberian volcanism shows a connection with the protracted stressful conditions in the aftermath of end-Permian mass extinction. Though a coincidence between the onset of the major eruptions and the extinction might be possible, it clearly requires more precise dating in which the error is less than the duration of the biotic event.

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