
Supplementary information

**Environmental crises at the Permian–
Triassic mass extinction**

In the format provided by the
authors and unedited

Supplementary Note 1

The magnitude of mass extinctions is expressed in terms of extinction rates. The extinction rate is usually calculated using marine taxa, which fossil record is richer and its age is better constrained, and varies depending on the used method. An extinction rate of at least ~81% for marine species has been calculated ¹ using an updated rarefaction method on Sepkoski's generic database ², and excluding biases of background extinction and the Signor-Lipps effect. The fossil record from the Meishan GSSP ³ shows extinction of 94% species ⁴. In South China, 93.3% of species didn't survive from the *C. meishanensis* to *I. staeschei* conodont zones ⁵, an interval of about ~60 kyrs across the PTB. Gap-filler extinction rate (r_{GF}) ⁶, which has high accuracy and precision, has been here calculated for Phanerozoic marine taxa from the Palaeobiology Database (Figure 1, main text). The time bins were defined by one or several neighbouring stages with roughly uniform span (average ~10 Myr) and the r_{GF} represents the total rate for the whole-time bin. r_{GF} is calculated using the following equation ⁶:

$$r_{GF} = \log\left(\frac{2T + pT}{3T + pT + GF}\right)$$

where GF represents the number of genera (gap-fillers) that were found in time bins i-1 and i+2 and not within bin i+1; r_{GF} represents gap-filler extinction rate; 2T represents the number of genera found before and within the present time bin; 3T represents the number of genera sampled in three continue time bins; and pT represents the number of genera found before and after but not within a time bin. Newly calculated Phanerozoic's GF extinction rates (Figure) show the PTME stands out as the most sever extinction event compared to other intervals. Along with the PTME, the Ordovician–Silurian, Frasnian–Famennian, end-Triassic, end-Cretaceous mass extinctions are usually regarded as the largest extinction events of the Phanerozoic, also known as the Big 5 (Figure 1, main text).

References

1. Stanley, S. M. Estimates of the magnitudes of major marine mass extinctions in earth history. *Proc. Natl. Acad. Sci. U. S. A.* **113**, E6325–E6334 (2016).
2. Sepkoski J. J., J. A compendium of fossil marine animal genera. Edited by David Jablonski and Michael Foote. *Bull. Am. Paleontol.* **363**, 1–560 (2002).
3. Yin, H., Zhang, K., Tong, J., Yang, Z. & Wu, S. The global stratotype section and point (GSSP) of the Permian-Triassic boundary. *Episodes* **24**, 102–114 (2001).

4. Jin, Y. G. *et al.* Pattern of marine mass extinction near the Permian-Triassic boundary in South China. *Science* (80-.). **289**, 432–436 (2000).
5. Song, H., Wignall, P. B., Tong, J. & Yin, H. Two pulses of extinction during the Permian-Triassic crisis. *Nat. Geosci.* **6**, 52–56 (2013).
6. Alroy, J. Accurate and precise estimates of origination and extinction rates. *Paleobiology* **40**, 374–397 (2014).