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Hot House Climate Following the End-Permian Mass Extinction

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The end-Permian mass extinction saw the most catastrophic diversity loss in the Phanerozoic. The extinction event was accompanied with a rapid temperature raise from 25 °C to 32 °C across the Permian-Triassic boundary. Oxygen isotope data measured from conodont phosphate in South China suggest that the temperature continued to increase in the Early Triassic and reached the first thermal maximum in the late Griesbachian. The late Griesbachian Thermal Maximum accompanied with the extinction of many Permian holdovers, such as the conodont *Hindeodus* and the ammonoid *Otoceras*. The following substage, the Dienerian, saw a 3-4 °C temperature decrease which coincides with a transient recovery pulse in which several groups began to diverstify. The early and middle parts of Smithian represent a relatively stable high temperature plateau but the late Smithian saw a further 2° C temperature increase to produce sea surface temperatures that exceeded 40° C during the Smithian-Spathian transition. The Late Smithian Thermal Maximum coincided with major diversity loss of marine nektons such as conodont and ammonoid. The Spathian saw an initial cooling trend followed by relatively stable temperatures in the middle part and further cooling at the end of this stage and stabilization of temperatures in the earliest Middle Triassic.

The Early Triassic record shows temperature consistently in excess of modern equatorial values. Such high temperatures would be expected to exert major impacts on lives both on land and in the ocean. Temperatures above 45°C cause protein denaturation for most animals and their response, to produce heat-shock proteins, can only delay death for a short interval. For water-breathing marine animals, the thermal limit is even lower because aerobic metabolic demands increase with temperature whilst oxygen solubility decreases in seawater and bodily fluids as temperature increases. Marine ectotherms with high performance and high oxygen demands, such as ammonoid cephalopods, suffered major diversity declines in the late Smithian Thermal Maximum. Nektonic vertebrates, such as fishes and ichthyosaurs, show both high mobility and low oxygen-dependent thermal tolerance. They could vacate the equator and migrate to more comfortable areas when temperature increases. These are clearly shown in the Early Triassic fossil record. Fish fossils are exceptionally rare in equatorial areas compared to those in high latitudes such as Spitsbergen and British Columbia. Similarly, for terrestrial tetrapods, most tetrapods assemblages were found in high latitude areas such as South Africa, Russia Federation and Antarctica. We suggest these fossil distribution patterns show exclusion for the equatorial life under hot house conditions in the Early Triassic.

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