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Two-stage marine anoxia and biotic response during the Permian–Triassic transition in Kashmir, northern India: pyrite framboid evidence

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Abstract

Although expanded ocean anoxia has long been believed to be a direct killing mechanism causing mortality of organisms during the Permian-Triassic mass extinction, little has been published on the extent and timing of this anoxia in Gondwana. The Guryul Ravine section in Kashmir, northern India, is a classic Permian–Triassic boundary (PTB) section containing high-quality marine sedimentary and fossil records, and thus provides a unique opportunity to study the redox conditions associated with the biotic crisis in the Gondwana region. Here, high-resolution biotic and redox data were generated from Kashmir to achieve an improved understanding of the nature of environmental stresses associated with the Earth's largest biocatastrophe. Our study, which evaluates pyrite framboid size and morphology, reveals two pronounced stages of oceanic oxygen deficiency, in the assigned latest Permian *Hindeodus praeparvus–Clarkina meishanensis* Zone and the earliest Triassic *Isarcicella staeschei* Zone. Updated marine invertebrate fossil records show three sharp species richness declines at Guryul Ravine. The first decline occurred within uppermost Permian storm beds and is interpreted to represent a facies control, in which a storm-agitated environment was inhospitable for benthos. The latter two biotic declines coincided with two marine anoxic events, as documented by pyrite framboid size distributions. The same two anoxic events are also recognized from PTB beds in the adjacent, relatively shallower Barus Spur section in Kashmir, in which newly obtained faunal data help to constrain placement of the PTB. The present study represents a new report of the two-stage pattern of oceanic anoxia during the Permian–Triassic transition. We propose that the two anoxic events at Guryul Ravine correlate precisely with anoxic events in the Meishan GSSP and some sections in South China, suggesting that this event sequence might have been characteristic of the Permian–Triassic transition in some specific geological settings. The close relationship between oxygen depletion and species richness decline suggests that the former were an important contributor to the latter. In addition, we find that many framboids exhibit surface oxidation, reducing their overall size. However, our statistical analysis suggests that the mean oxidation-related reduction in size is less than 2.2%, thus having little effect on redox interpretations based on pyrite framboid sizes. Our results demonstrate that, unlike many geochemical proxies, the pyrite framboid technique is still valid for redox interpretations of weathered samples.