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Persistent Oxygenation in Shallow-Marine Settings of the Western Tethys During the Permian-Triassic Mass Extinction

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The largest mass extinction of the Phanerozoic, at the Permian-Triassic boundary, is commonly linked to rapid warming, water column stratification, and severe “global” oceanic anoxia. However, oxygen loss models [1] suggest that anoxia was a heterogeneous event, and its global extent, especially in site-specific studies, remains poorly understood. In this study, we analyze rare earth elements, yttrium, trace metals including manganese from the carbonate fraction, alongside carbon, oxygen, and strontium isotopes, as well as total organic carbon (TOC) content, in two well-dated and exceptionally preserved shallow-marine sedimentary records from the equatorial western Tethys Ocean (Central Iran). The Late Permian is characterized by fossiliferous, medium-bedded limestone in both sections (Hambast Formation). The extinction horizon is overlain by a 2 m-thick microbialite interval in the classical Abadeh section and by black shales in the nearby Baghuk section. The earliest Triassic in both sections is marked by thin-bedded, dark gray limestone (i.e., Elika Formation).

Our data indicate that well-oxygenated marine conditions persisted from the Late Permian across the extinction horizon and into the overlying microbialite and black shale intervals in the western Tethys, which aligns well with modeled data. Mn, U/Al, and Th/U ratios suggest a slight shift toward less-oxygenated conditions in the overlying Elika Formation, coinciding with a rapid sea-level rise in the earliest Triassic. This observation highlights the role of shallow water depth and photosynthetic cyanobacteria in sustaining oxygen levels in the Tethyan realm. Additionally, a dramatic decline in paleoproductivity, beginning well before the extinction horizon (as indicated by enrichment factors of Zn, Ni, and P), suggests that oxygen consumption via organic matter remineralization was insufficient to drive oxygen deficiency and anoxia.

In conclusion, the shallow-marine setting of the equatorial western Tethyan realm remained well-oxygenated during the Permian-Triassic mass extinction due to its low depth, sustained photosynthetic activity, and reduced nutrient supply to equatorial surface waters. While deep-marine settings in both the Panthalassa and Tethys Oceans were severely anoxic, shallow-marine settings in the Tethys Ocean may have served as a refuge.

[1] Penn et al., 2018. Temperature-dependent hypoxia explains biogeography and severity of end-Permian marine mass extinction. Science 362, 6419.