Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36839

Spatially Variable Redox and Nutrient Cycling Across the Cryogenian–EdiacaranTransition

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The Cryogenian–Ediacaran transition witnessed major redox and biogeochemical transformations. Yet, the coupling between rising O_2 in the oceans and the atmospheric and nutrient fluxes sustaining time-equivalent biological innovations remains unresolved. Elucidating the redox-nutrient pairing processes is crucial for reconstructing environmental controls on early eukaryotic evolution. While individual redox and nutrient proxies have been studied, integrated multi-isotope constraints across basins are lacking. This study investigates the Cd-Cr isotope tracer recorded in authigenic carbonates from the Neoproterozoic Witvlei Group (Kalahari Craton), in conjunction with a global perspective from the Yangtze Platform, the Amazonian, São Francisco, and Rio de la Plata Cratons. Our results reveal low productivity and anoxia during Cryogenian glaciations, followed by asynchronous postglacial redox stabilization and nutrient utilization across different regions with long-term rises in atmospheric oxygenation and primary productivity. The Shuram (Shuram–Wonoka) excursion is characterized by widespread but regionally variable negative $\delta^{13}C$ excursions and relatively lower Cd-Cr isotope compositions, indicating transient redox instability and nutrient stress. Toward the late Ediacaran, surface oxygenation appears to have progressively stabilized. These findings show that redox evolution and nutrient cycling across the Cryogenian–Ediacaran transition were tightly coupled but progressed unevenly across paleo-continents. We therefore propose that the observed patchiness of Ediacaran animal evolution was governed by asynchronous environmental tipping points across different continental shelves, rather than a uniform global redox and nutrient stabilization.