Goldschmidt 2024 Abstract
https://doi.org/10.46427/gold2024.21688

Identifying bottom euxinia in lacustrine environments: Paired nitrogen-sulfur isotopic systematics, iron chemistry, and implications for oceans in the geological past

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Euxinia, a crucial redox condition of aquatic environments, represents the most severe deoxygenation episodes in Earth's history. While a series of redox proxies have been explored and applied to the investigation of paleoredox conditions, most of them are utilized to reconstruct the atmospheric pO2 (e.g., δ^{53}Cr, δ^{98}Mo, Ce/Ce*), the proportion of anoxic water relative to the entire ocean (e.g., δ^{238}U), and (de)oxygenation events [e.g., I/(Ca+Mg) ratio]. Only a handful, such as Fe speciation and Mo-U concentrations, hold the capacity to specifically indicate local euxinia in certain regions. Here, we conduct systematic investigations on the Triassic Chang 7 Member in the Ordos Basin, North China. While the basin was widely considered anoxic throughout the Chang-7 interval, several studies have suggested oxic settings. Furthermore, Fe speciation analyses indicated a ferruginous rather than euxinic condition, despite the presence of abundant pyrite content (up to 47.4%) and Mo-U enrichment (100s Mo_{EF} and 10s U_{EF}). To address this discrepancy, we propose a novel approach that couples total nitrogen isotopes ($\delta^{15}N_{TN}$) and pyrite sulfur isotopes ($\delta^{34}S_{py}$) to delineate the location of the sulfate reduction zone through a series of Rayleigh distillation and one-dimensional diffusion-advection-reaction simulations. This new technique suggests widespread bottom euxinia during the onset of the Chang-7 interval, followed by rapid contraction through this period. Additionally, we identify magnificent diagenetic alteration of Fe speciation, which could lead to lower Fe_{py}/Fe_{HR} ratios and account for the underestimated extent of anoxia in previous studies. These findings present an innovative method for tracing benthic euxinia, probably applicable to ancient marine environments, since the expected coupling of $\delta^{15}N_{TN}$-$\delta^{34}S_{py}$ systematics is also observed in modern and Ediacaran-Cambrian oceans.