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Iron (Ⅲ)-mediated Early-Diagenesis Overprints on Ediacaran Shuram Excursion

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The Ediacaran Shuram excursion, Earth's largest carbon isotope anomaly, is widely attributed to a net oxygenation of the oceanic organic carbon pool. However, the temporal and spatial variability of the Shuram excursion casts uncertainty on the primary carbon isotope signals and the extent of oxidation they represent. Here, we investigate the mechanisms underpinning the Shuram excursion by selecting the Jiulongwan section, a well-preserved and stratigraphically representative record in South China. We analyzed carbonate-associated manganese (Mn_{carb}) and ferrous iron (Fe_{carb}) concentrations along with molybdenum isotope compositions to explore the Mn-Fe-S cycle and its role in shaping the Shuram excursion.

Carbonate geochemistry reveals an increase in Fe_{carb} and a decrease in Mn_{carb} contents, indicating a transition from manganous (Mn-reducing) to ferruginous (Fe-reducing) conditions near the sediment-water interface. Light and variable Mo isotope compositions, coupled with persistently low Mo concentrations, suggest limited H_2S availability and a sulfate reduction zone restricted to sediment porewaters. These findings indicate that sulfate-mediated organic remineralization was confined to sediments rather than occurring in the water column. A geochemical equilibrium model further demonstrates that the observed δ^{13}Ccarb decrease of ~8‰ cannot be sustained by sulfate reduction alone without requiring unrealistically high pyrite burial (>4 wt.%). However, incorporating Fe(III) reduction into the model is essential to reconcile the δ^{13}Ccarb values with the observed pyrite content (1.1 ± 0.7 wt.%). This confirms that Fe(III)-mediated anaerobic oxidation of organic matter played a crucial role in driving the Shuram excursion at Jiulongwan.

These results indicate that the Shuram excursion at Jiulongwan does not require extensive oceanic oxygenation but can be best explained by redox-sensitive early diagenetic processes. Notably, a regional increase in Fe-Mn oxide contents could also have contributed to the excursion and may have led to a shift in the oxidative thresholds of benthic environments. Such a transition could have facilitated the rise of complex benthic organisms, enabling processes such as biomineralization and bioturbation. The strong influence of Fe(III) reduction underscores the importance of distinguishing primary seawater signals from post-depositional overprints when interpreting major carbon cycle perturbations in Earth's history.