

Sulfur cycle dynamics during the Great Oxidation Event

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During the early Paleoproterozoic, the Earth system has seen a series of environmental changes, including severe glaciations and a dramatic increase in atmospheric oxygen (O₂) levels (Great Oxidation Event; GOE). The oxygenation of Earth surface environment would be a primary driver of biological evolution by reshaping the landscape of biogeochemical cycles. The recent constraint on the sulfur isotopic records in the aftermath of the third glaciation (Gowganda/Rooihogte Formations) implies an intimate link between the glaciation and the GOE (2.33 Ga). However, the biogeochemical dynamics throughout the GOE is still puzzling.

Here we use a numerical model of the global biogeochemical cycles of carbon, phosphorus, sulfur and oxygen to examine the mechanistic explanation for the large negative excursion of sulfur isotope of pyrite ($\delta^{34}\text{S}_{\text{py}}$) shortly after the GOE. We paid a special attention to the sulfur cycle dynamics because sulfur isotope data provides powerful quantitative constraints on the redox-driven biogeochemical cycles in Earth surface environment. We explore the impact of varying key model parameters using a stochastic approach and find that the extremely high atmospheric CO₂ levels (>0.2 atm) would be required as an initial condition (in the aftermath of the glaciation) to cause a sufficient negative anomaly within 10-20 Myr after the glaciation. This implies that the third glaciation was a snowball earth event. Our model also provides a series of testable predictions, including a secular positive excursion of $\delta^{34}\text{S}$ of both seawater sulfate (+20–30 permil) and pyrite (+0–5 permil) and a buildup of seawater sulfate to >1 mM on the timescale of 10⁷ years. These model predictions should be tested by the geologic records.