Local environmental variations obscure the interpretation of pyrite sulfur isotope records

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The sulfur biogeochemical cycle plays a key role in regulating Earth's surface redox evolution via dissimilatory microbial sulfate reduction (DSR). Because DSR generates significant isotope fractionation among sulfur species, sulfur isotope of sedimentary sulfide, more specifically the pyrite sulfur isotope ($\delta^{34}S_{py}$), are used to reconstruct the paleocean redox in geological time scale. In the canonical sulfur cycle model, $\delta^{34}S_{py}$ reflects the degree of pyrite burial that is mainly controlled by the global ocean redox condition. However, $\delta^{34}S_{py}$ shows wide ranges of stratigraphic variation within short intervals (< 1 Ma), which cannot be resolved by the sulfur cycle model. In this study, we develop a numerical model to simulate the process of syndepositional pyrite formation within sediment porewater, and to quantify $\delta^{34}S_{py}$ and pyrite content in sediments. The modeling results indicate that global ocean redox condition, e.g. seawater sulfate concentration, is not the only control of $\delta^{34}S_{py}$, instead, some local factors, such as organic matter content, sedimentation rate, and the redox at seafloor certainly matter. Our model testifies generally high $\delta^{34}S_{py}$ values of Proterozoic pyrite as a consequence of low seawater sulfate concentration, while failure of simulating superheavy pyrite precipitation by the steady state model implies that superheavy pyrite with persistent stratigraphic occurrences cannot be generated by dissimilatory microbial sulfate reduction (DSR) within sediment porewater. The modeling results also suggest that $\delta^{34}S_{py}$ is a rather local proxy and cannot be used to trace the global ocean redox condition. Finally, we propose that the marine redox landscape could be better constrained when combining $\delta^{34}S_{py}$ and pyrite content.