New marine sulfur cycle model after the Snowball Earth glaciation

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The Sturtian Snowball Earth glaciation (~717-660 million years ago) represents the most severe icehouse climate in Earth's history. Geological evidence indicates that, during this glaciation, ice sheets extended to low latitudes, and model simulations suggest global frozen oceans as well as a prolonged shut-down of the hydrological cycles. The Snowball Earth hypothesis poses that the Sturtian global glaciation is directly triggered by intense continental weathering that scavenges atmospheric CO_2, while the global frozen condition is terminated by extremely high atmospheric CO_2 levels (~350 times present atmospheric level), which is perpetuated by synglacial volcanic eruptions for tens of million years. The deglaciation is an abrupt process, lasting for hundreds to thousands of years, and the sharp transition to a hothouse condition is accompanied with extremely high weathering rates and followed by perturbations of the marine sulfur cycle.

Unusual perturbation of the marine sulfur cycle after the Sturtian glaciation is hinted at worldwide precipitation of isotopically superheavy sedimentary pyrite (FeS_2) in the interglacial sediments. In the classic sulfur cycle framework, pyrite, the predominant sulfide mineral in sediments is always depleted in ^{34}S as compared with seawater sulfate, because sulfate reducing microbes preferentially utilize ^{32}S enriched sulfate to generate sulfide. However, a compilation of pyrite sulfur isotope data shows extremely high values (up to +70%, obviously higher than coeval seawater sulfate values) in the aftermath of the Sturtian glaciation. Although superheavy pyrite is also reported in other geological periods, the Cryogenian interglacial interval after the Sturtian glaciation represents the only time with superheavy pyrite formation in a global scale for ~10 million years. The traditional theoretical sulfur cycle model does not satisfactorily address the long-term and global occurrence of superheavy pyrite in the Cryogenian interglacial interval.

Dr. Lang and his colleagues proposed a novel sulfur cycle model that incorporates volatile organosulfur compounds (VOSC) to interpret the global occurrence of superheavy pyrite after the Sturtian glaciation. They carried out detailed petrographic observations and paired pyrite content and sulfur isotope data of superheavy pyrite from the Cryogenian interglacial deposits of the Datangpo Formation in South China. Both the petrographic and geochemical data from South China indicate that the Cryogenian interglacial oceans were mainly sulfidic (anoxic and H_2S enriched). In sulfidic conditions, volatile organosulfur compounds (VOSC) could be pervasively generated via sulfide methylation. Because the VOSC always has a lower sulfur isotope value relative to seawater sulfate, continuous VOSC emission would elevate sulfur isotope of residual sulfur pool of sulfidic seawater, resulting a vertical isotopic gradient of seawater and the precipitation of superheavy pyrite near/at seafloor.

Their findings demonstrate that superheavy pyrite formation requires both high microbial sulfate reduction and VOSC formation rates so as to maintain such unusual perturbation of marine sulfur cycle. As organic matter and sulfate are prerequisites for these reaction, ~10 million-year occurrences of superheavy pyrite may suggest continuous high primary productivity and intense continental chemical weathering after the Sturtian glaciation. These findings improve our understanding of the Snowball Earth event and ancient marine sulfur cycle.

More information: Xianguo Lang et al, Cracking the superheavy pyrite enigma: possible roles of volatile organosulfur compound emission, *National Science Review* (2021). DOI: 10.1093/nsr/nwab034

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