Sturtian meteoric and marine ice volume constrained by oxygen isotopes in marine Fe oxides

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Neoproterozoic low-latitude glaciations ("Snowball Earth" episodes) represent some of the most severe climatic perturbations in Earth history. There is no agreement about the exact nature of these events, highlighting uncertainty in our basic understanding of the physical climate system. The extent of the oceans' ice cover, the amount and distribution of meteoric and marine ice, and the synchronous occurrence of the glaciation worldwide are all topics of intense debate. This uncertainty stems, at least in part, from the absence of direct observational constraints on these fundamental aspects of the Neoproterozoic glaciations.

We address this knowledge gap using the oxygen isotope composition of iron oxides from marine iron formations deposited during the Sturtian glaciation (717-661 Ma), the first of two proposed Neoproterozoic glaciations. Iron oxides are geologically abundant, resistant to oxygen isotope exchange under most conditions, and display a weak temperature-dependent water-oxide oxygen isotope fractionation. Thus, well-preserved marine iron oxides are expected to track the oxygen isotope composition of seawater. By measuring the isotopic composition of iron oxides before (~900 Ma), during (~700 Ma) and after (~520 Ma) the Sturtian glaciation, we constructed an isotopic mass balance of the hydrosphere. Together with independent estimates of sea-level changes associated with the Sturtian glaciation and of the isotopic composition of meteoric ice, the isotopic mass balance constrains the total amount of ice and the fractions of meteoric and marine ice out of the total.

The isotopic mass balance suggests that at least 20%, and most likely about one third of Earth's hydrosphere was locked up in ice. Approximately half of the ice was meteoric, derived from an atmospheric hydrological cycle despite the extremely low temperatures, and half marine, derived from freezing of seawater. The largest source of uncertainty on these results is the estimate of sea-level fall during the glaciation. We will discuss these results and implications for our understanding of the Snowball Earth events.