Coupled ^{18}O-Hf-U/Pb in zircons as evidence for Archean to Proterozoic continental weathering conditions

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The Archean and Proterozoic Eons witnessed some of the most dramatic perturbations to Earth's otherwise relatively stable carbon cycle and climate, including the Snowball Earth glaciations. Despite decades of research into the causes of these events and their relevance for understanding Earth's habitability, they remain fundamentally enigmatic. Here we propose that the isotopic composition of zircons may provide constraints on key fluxes in the carbon cycle during these periods of time. Specifically, we suggest that the oxygen stable isotope composition ($\delta^{18}O$) in detrital zircons contains information about past weathering conditions on the continents. Together with time constraints from radiogenic isotopes in the same grains, this information may help shed new light on the Archean and Proterozoic carbon cycle.

In this work, we present a new compilation of published isotope data from >4500 zircon grains which have been analyzed for $\delta^{18}O$, εHf, and U/Pb ages. We use the difference between the Hf model age and the U/Pb crystallization age for a given grain ($\Delta T_{Hf\text{-}U/Pb}$) to constrain the time interval during which $\delta^{18}O_{zircon}$ may have been altered by assimilation of altered crustal material. We suggest that more alteration during a given $\Delta T_{Hf\text{-}U/Pb}$ (i.e., higher $\delta^{18}O$) indicates more intense chemical weathering during that time interval. We find that the mean $\delta^{18}O$ value has changed with time, varying particularly between 2.5 Ga and 0.5 Ga. The maximum in the zircon $\delta^{18}O$ record occurs at the same time as the Lomagundi Event, which could mean intense chemical weathering at the time. This interpretation is consistent with the Lomagundi carbon isotope excursion reflecting enhanced organic carbon burial facilitated by the release of phosphorous during rock weathering. In contrast, the minimum in zircon $\delta^{18}O$ occurs at the same time as the Neoproterozoic Snowball Earth events. This coincidence suggests low weathering rates at the time, in contrast to hypotheses of high weathering rates enhancing drawdown of atmospheric CO_2 and causing glaciation. The zircon evidence instead suggests that low rates of CO_2 release to the atmosphere from solid Earth degassing may have preconditioned the global climate system for glaciation.