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High hydrothermal input into Archean oceans and its potential link to mantle evolution before the Great Oxidation Episode (GOE)

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The evolution of deep-water hydrothermal influx through geological time is critical for our understanding of submarine volcanic activities in the deep time ultimately linked to mantle temperature and convection. To address this topic, Europium (Eu) anomalies in rare earth element (REE) patterns have been investigated in various chemical sedimentary rocks through time. Europium is a redox-sensitive REE that can be reduced from +III to +II under highly reducing conditions, high temperature (>200°C), and mildly acidic conditions typical of hydrothermal cells developed at modern mid-ocean ridges. This redox behavior generates positive Eu anomalies that are systematically measured in modern deep-sea hydrothermal fluids and associated precipitates, but absent in modern seawater. Archean BIFs typically carry pronounced positive Eu anomalies, which argue for generally higher hydrothermal inputs into the early oceans. Beyond this, secular trends in the amplitude of Eu anomaly in BIFs suggest enhanced hydrothermal activity at ca. 2.5-2.7 Ga, right before the GOE, followed by a general decrease throughout the Proterozoic. The magnitude of Eu anomaly however strongly varies within a single deposit, complicating interpretation of this proxy.

To provide a new perspective on this topic, we explored whether Eu stable isotope ratios could be used as a tracer of submarine hydrothermal activity. We report here the first d^{153}Eu results for modern and Archean chemical sedimentary rocks. Significant Eu isotopic fractionation (d^{153}Eu up to 0.25‰) was measured in modern hydrothermal deposits, while modern hydrogenetic nodules have average d^{153}Eu values near-to-zero, similar to those for all igneous and terrigenous sedimentary rocks measured so far [1]. Archean BIFs from Canada, Australia, South Africa, and Greenland all show positive d^{153}Eu values, confirming that high-temperature hydrothermal influx was indeed much larger in the Archean oceans. Some of the isotopic variability is likely to reflect terrigenous contamination. The Eu isotopic composition of the least-contaminated BIFs, representative of seawater composition, appears surprisingly stable until the end of the Archean, arguing against a peak in mantle activity just before the GOE as suggested by Eu anomalies. Overall, stable Eu isotope composition seems to be a promising tracer to quantify hydrothermal input into the oceans.

[1] Nicol et al.,*JAAS*,2023