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Oxidative Mo cycling in the Mesoarchean: new insights from the 2.87 Ga Red Lake platform

MRS. AMANDINE L. E. MIGEON[1], MUNIRA AFROZ[1], LAURELINE PATRY[1], PIERRE BONNAND[2], PIERRE SANS-JOFRE[3], PHILIP W. FRALICK[4] AND STEFAN V. LALONDE[1]

[1]UBO, CNRS-UMR6538 Laboratoire Geo-Ocean
[2]CNRS-UMR6538
[3]IMPMC, CNRS, Sorbonne Université, MNHN
[4]Lakehead University

Prior to 2.5 Ga, Earth's oceans were largely anoxic except for localized oxygen oases in shallow marine environments. The 2.87 Ga Ball Assemblage of the Red Lake Greenstone Belt (Ontario, Canada) preserves one of the oldest thick carbonate platforms on Earth, and abundant industry drill core available at this locality offer unique opportunities for investigating Mesoarchean redox conditions. Previous outcrop-based studies identified negative Ce anomalies and heavy Mo isotope signatures, suggesting transient oxygenation at Red Lake [1, 2], further supported by La-Ce geochronological data that confirm that the Ce anomalies formed syn-depositionally [3]. In this work we sought to better understand Mesoarchean oxidative Mo cycling via detailed Mo isotope chemostratigraphy realised on two correlative drill cores. Mo isotope values across microbialitic dolomites and calcites, oxide-facies iron formations (IF), black shales, and sulfidic black shales range from -2.22‰ to 0.53‰, indicating significant redox-driven Mo fractionation as early as 2.87 Ga. Despite authigenic Mo enrichment in IF and carbonates relative to crustal values, Mo concentrations remain low, consistent with a small seawater Mo reservoir. Carbonate Mo isotopes are generally unfractionated from crustal values, suggesting a near-zero $\delta^{98/95}$Mo composition for Mesoarchean seawater. These observations indicate that incipient oxidative Mo cycling did not generate an isotopically heavy Mo reservoir, in contrast to modern oceans. We develop a steady-state isotope mass balance model that demonstrates how a near-zero $\delta^{98/95}$Mo seawater reservoir is the expected outcome under reduced riverine Mo inputs, elevated hydrothermal fluxes, and variable reservoir sizes, providing important perspective on the application of Mo isotope redox proxies at the onset of Earth system oxygenation.

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