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Increase in Magma Redox States Across the Great Oxidation Event Revealed by Uranium XANES Oxybarometry of Zircon

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The Great Oxidation Event (GOE) represents a major transition in Earth's surface environment, yet the relationship between atmospheric oxygenation and the redox evolution of the continental crust remains uncertain. While potential connections between atmospheric and mantle redox histories have been widely investigated, the oxidation state of the crust, which links these reservoirs, has received comparatively less attention. Determining whether crustal redox changes preceded, accompanied, or followed atmospheric oxygenation is, however, critical for resolving the mechanisms that drove the GOE.

Here, we apply a recently developed oxybarometer based on X-ray absorption near-edge structure (XANES) analysis of uranium in zircon [1] to samples spanning the Archean-Proterozoic transition (~3.0-1.5 Ga). Because uranium valence can be quantified by U XANES, and zircon can be precisely dated by U-Pb geochronology, this approach allows magma redox information to be obtained from the same element, within the same mineral grain, from which crystallization ages are determined.

Our results indicate an overall increase in magma fO_2 across the ca. 3.0-1.5 Ga interval, from average values below the fayalite-magnetite-quartz redox buffer (FMQ) in the Archean to above FMQ in the Proterozoic. The timing of this transition broadly correlates with other fundamental changes to the continental crust, such as the shift from dominantly TTG to high-K magmatism, widespread continental emergence, and cratonization. Notably, the sustained rise in magma fO_2 begins at ~2.5 Ga, prior to the nominal age of the GOE (~2.4-2.1 Ga). Because oxidized surface materials require tens to hundreds of millions of years to be recycled into the mantle or remelted within the crust, a substantial lag between atmospheric oxygenation and crustal oxidation would be expected if the GOE were driven solely by enhanced biologic O_2 production. The generally synchronous timing between increasing magma fO_2 and independent indicators of atmospheric oxygenation (e.g., the disappearance of sulfur mass-independent fractionation) suggests that changes in the nature of the continental crust were an important factor in driving the GOE and highlights the role of crustal processes in modulating long-term atmospheric composition.

[1] Houchin et al. (2024), *Geochimica et Cosmochimica Acta*.