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Tracking pre-GOE ocean oxygenation using thallium isotopes from South American sedimentary records

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The progressive evolution of Earth's surface environments fundamentally shaped atmospheric oxygenation, nutrient cycling, and the rise of biological complexity, culminating in the Great Oxidation Event (GOE; ~2.4–2.3 Ga). While atmospheric oxygenation is relatively well constrained, the timing, spatial extent, and mechanisms of ocean redox evolution prior to the GOE remain poorly understood. Most pre-GOE redox reconstructions rely on sedimentary successions from Western Australia and South Africa, likely deposited within the same marine basin, raising questions about the global extent of these records. Here, we present thallium (Tl) isotope data from sedimentary successions deposited in distinct cratonic settings: Neoarchean (~2.68 Ga) shales and siltstones from the Serra Sul Formation (Carajás Basin, Amazonian Craton) and Paleoproterozoic (~2.5 Ga) shales from the Batatal Formation (Minas Basin, São Francisco Craton). Thallium isotopes track Mn-oxide burial in marine sediments due to strong isotope fractionation during adsorption to Mn oxides, whereby the heavy Tl isotope is preferentially removed from seawater. Because Mn-oxide formation requires dissolved oxygen, Tl isotope compositions of anoxic sediments that quantitatively record seawater values provide an indirect proxy for ocean oxygenation. Neoarchean samples from the Carajás Basin display Tl isotope compositions that fall within uncertainty of crustal values, indicating the absence of globally significant Mn-oxide burial and predominantly reducing depositional conditions despite independent evidence for cryptic oxygen cycling at ~2.68 Ga [1]. In contrast, Paleoproterozoic shales from the Batatal Formation exhibit Tl isotope compositions significantly lighter than crustal values, consistent with an operational Mn cycle and enhanced Mn-oxide burial. The magnitude of this signal overlaps with coeval records from the Mt McRae Shale (Pilbara Craton, Western Australia)[2] and the Klein Naute Formation (Kaapvaal Craton, South Africa)[3]. Together, these data support a transition from localized oxidative environments in the late Archean (2.68–2.63 Ga) to globally expressed oxygenated conditions by ~2.5 Ga.

[1] Pellerin et al. (2024), *Nature* 633, 365-370; [2] Ostrander et al. (2019), *Nature Geosciences* 12, 186-191; [3] Chen et al. (2025), *Nature Geosciences* 18, 423-429