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Multiple sulfur isotopes in Eoarchean arc lavas record the early onset of volatile cycling at subduction zones

GUILLAUME CARO[1], THOMAS GROCOLAS[2], PHILIP BOURGEOIS[1], PIERRE BOUILHOL[1], STEPHEN JAMES MOJZSIS[3] AND GUILLAUME PARIS[1]

[1]Université de Lorraine, CNRS, CRPG
[2]University of Lausanne
[3]Research Centre for Astronomy and Earth Sciences (CSFK)

The timing of subduction initiation, a key driver of Earth's geodynamics, remains debated due to the scarcity of well-preserved geological records from the early Earth. Here, we present geochemical evidence indicating that subduction-related processes were active as early as 3.8 Ga, based on sulfur ($\Delta^{33}S$, $\delta^{34}S$) and neodymium ($\mu^{142}Nd$, $\varepsilon^{143}Nd$) isotope signatures from arc-like amphibolites (meta-lavas) of the Innuksuac Complex (3.6-3.8 Ga, Quebec, [1]).

We conducted high-precision sulfur isotope analyses using multi-collector inductively coupled plasma mass spectrometry. The samples exhibit pervasive mass-independent sulfur isotope anomalies, a hallmark of atmospheric photochemical reactions in an anoxic environment. Systematic correlations between $\Delta^{33}S$ and immobile trace element ratios (e.g., Zr/Y, Dy/Yb) confirm that these anomalies are primary features of the protoliths. These relationships further indicate that Innuksuac lavas formed through hydrous mantle melting triggered by sediment devolatilization at relatively shallow depths within the spinel peridotite stability field.

Additionally, we measured ^{142}Nd isotopic compositions via thermal ionization mass spectrometry to identify signatures of early crustal differentiation. Our results show that the negative $\mu^{142}Nd$ anomalies characterizing the Innuksuac Complex, including the Nuvvuagittuq and Ukaliq supracrustal belts, are tightly correlated with thorium enrichments, mirroring the $^{143}Nd/^{144}Nd$ vs. Th/Nd relationship observed in modern continent-margin subduction environments. Collectively, these observations suggest that the $\Delta^{33}S$ and $\mu^{142}Nd$ signatures in the Innuksuac volcanic rocks reflect the influx of sediment-derived fluids and melts into the sub-arc mantle, resulting from the recycling of terrigenous sediments from a Hadean proto-continent.

These results challenge the prevailing view that subduction began operating in the late Archean and suggest that plate tectonics may have emerged significantly earlier. The evidence for active subduction at 3.8 Ga indicates that fundamental biogeodynamic processes, including continental growth, as well as volatile and sediment cycling at subduction zones, were already established in the Eoarchean, and possibly in the Hadean, shaping the evolution of Earth's atmosphere, hydrosphere, and potentially its early biosphere.

[1] Grocolas T., Bouilhol P., Caro G. and Mojzsis S. J. (2022) Eoarchean subduction-like magmatism recorded in 3750 Ma mafic–ultramafic rocks of the Ukaliq supracrustal belt (Québec).