SSAGI 2026
XIV SOUTH AMERICAN SYMPOSIUM ON ISOTOPE GEOLOGY
Montevideo (Uruguay), 13-16 April

WHY YOUR ZIRCON HF MODEL AGES MIGHT BE WRONG—AND HOW TO FIX THEM

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The geodynamic setting and source characteristics of magmatic suites are primary controls on the fertility of metallogenic systems, particularly porphyry Cu-Au deposits. The genesis of these systems typically requires the intersection of specific petrogenetic factors: the generation of oxidized, hydrous magmas and the efficient extraction of metals from a source reservoir.

In this context, the ratio of juvenile mantle-derived melt to reworked ancient crust is a critical indicator of mineralizing potential. High proportions of juvenile input often correlate with the introduction of gold and copper into the upper crust, whereas excessive crustal contamination can modify the oxidation state and sulphur solubility of the melt, potentially sequestering metals in the lower crust. Therefore, the ability to accurately define isotopic end-members is not merely a petrological exercise; it is essential for identifying fertile magmatic arcs. If mantle evolution models are poorly constrained, the resulting miscalculation of crustal residence times can obscure the relationship between tectonic triggers, such as slab melting or lithospheric delamination, and the specific metallogenic pulses they produce.

Precise characterization of end-member compositions is fundamental to estimating the relative proportions of juvenile mantle input versus reworked crustal material within magmatic systems. Over the past two decades, the integration of zircon U-Pb geochronology with Hf (± O) isotope geochemistry has emerged as the primary analytical framework for addressing these petrogenetic inquiries. However, accumulating isotopic data from various terranes suggest that the depleted mantle may not follow a conventional linear evolutionary path from a primordial composition at ~4.5 Ga toward a modern, radiogenic Mid-Ocean Ridge Basalt (MORB) reservoir. Instead, isotopic records from several cratonic regions reveal that the most radiogenic Hf signatures converge with the chondritic uniform reservoir (CHUR) at significantly younger ages. In the Fennoscandian Shield, the temporal trajectory of these radiogenic signatures intersects the chondritic reference at approximately 3.5 Ga. This intersection is coeval with the age of the oldest identified crustal material in the region, suggesting initial differentiation of incompatible elements (initial depletion) of the sub-Fennoscandian mantle at this time.

Interpreting zircon Hf isotope data using mantle reference curves tailored to the geological evolution of each region, rather than applying a generic globally linear depleted mantle model since 4.5 Ga, transforms the inferred crustal growth record. Such regionally informed models remove the requirement for implausibly long crustal residence times between early extraction and later felsic differentiation. They instead produce crustal growth peaks that align with known orogenic events, including the 2.8–2.6 Ga Lopian/Karelian orogeny, the 2.0–1.8 Ga Svecokarelian orogeny, and a smaller peak coinciding with the Gothian orogeny. Comparable

patterns are observed in the East Pilbara Terrane, Australia, and in southern West Greenland, where initial crustal extraction at ca. 3.6 Ga and 3.85 Ga, respectively, overlaps with chondritic zircon Hf signatures in the oldest rocks. Newly compiled zircon Hf isotope data from north-central Argentina similarly reveal few data points that are compatible with extraction from a MORB depleted mantle source but rather reveal a regional isotope signature compatible with either mantle enrichment or a mildly depleted source. Furthermore, a regional mantle composition generates crustal growth periods that better mirror the known tectonic evolution of the region.

A critical component of extracting meaningful geological insights from zircon Hf isotope datasets is rigorous analytical practice. High analytical precision, accurate correction procedures, and consistent data screening are essential, as even minor lapses in analytical rigour may generate false or highly misleading isotope signatures. Analytical "noise" or poor corrections can mistakenly be interpreted as regional mantle variations. Such inaccuracies can propagate through models, leading to erroneous interpretations of crustal residence times, mantle depletion ages, and crustal growth peaks. Ensuring robust analytical protocols is therefore fundamental for reliably reconstructing any isotope-based models.

Ultimately, shifting toward regionally constrained curves reconciles the importance of using regionally constrained mantle evolution curves and maintaining stringent analytical standards. Together, they provide a framework that better reconciles zircon Hf isotope data with the known tectonic histories of diverse cratonic blocks and yields more geologically plausible models of early continental growth.

Keywords: Zircon $\delta^{18}O$, zircon Lu-Hf, zircon U-Pb, crustal evolution, MORB