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Simple Lu–Hf isotope patterns resulting from complex Archean geodynamics: example of the Pietersburg block (South Africa)

Oscar Laurent (1) and Armin Zeh (2)

(1) University of Liège, Département de Géologie, Liège, Belgium (olaurent@ulg.ac.be), (2) J.W. Goethe University, Institut für Geowissenschaften, Frankfurt am Main, Germany

The combined use of U–Pb and Lu–Hf isotope data from Hadean and Archean zircons is widely used to constrain the mechanisms of continental crust formation and evolution in the early Earth. Such data generally define εHf-time arrays, interpreted as reflecting the closed-system, protracted reworking of single crustal reservoirs episodically extracted from depleted mantle (DM) sources. Many models about early Earth evolution and continental growth rely on this interpretation and its consequences (i.e. determination of Hf model ages and crustal residence times).

However, this straightforward interpretation is difficult to reconcile with the complex evolution of Archean terranes, involving progressive crustal maturation and a range of crustal and mantle sources to granitoid magmas. Here we present a database of U–Pb and Lu–Hf isotopes measured in situ by LA-(MC-)ICPMS in zircons from >30 samples, representative of the temporal and spatial record of a single segment of Archean crust, the Pietersburg block (Kaapvaal Craton, South Africa). Coupling of age-Hf data with petrological and geochemical constraints shows that >1 Ga-long crustal evolution in the PB is characterized by (i) crustal nucleation in an intra-oceanic setting between 3.4 and 3.1 Ga; (ii) rapid formation of large volumes of juvenile TTG crust in an accretionary orogen at the northern edge of the proto-Kaapvaal craton between 3.1 and 2.9 Ga; (iii) intracrustal reworking and subduction of TTG-derived sediments along an Andean-type continental margin between 2.9 and 2.75 Ga; (iv) continental collision with the Central Zone of the Limpopo Belt at 2.75–2.69 Ga, resulting in magmatism derived from local crust and metasomatized mantle; (v) a discrete anorogenic event at $\sim$2.05 Ga with the emplacement of SCLM-derived alkaline magmas.

Despite the diversity of magmas and geodynamic settings depicted by this evolution, all samples emplaced between 3.0 and 2.0 Ga plot along a single, robust array of decreasing εHf with time, demonstrating that such arrays do not provide relevant information about Hadean-Archean geodynamics, unless independent constraints are considered. The Hf-time array of the PB is moreover characterized by a notably low 176Lu/177Hf of $\sim$0.003, typical of the $\sim$2.95 Ga-old TTGs that represent the largest volume of juvenile crust in the area. Yet, the petrogenesis of granitoid magmas plotting along the array involve other source components and crust-mantle interactions. This paradox may be solved considering that the bulk crust-mantle system behaved as a closed-system reservoir for Lu/Hf once large volumes of TTG crust and complementary SCLM were formed, enhancing the stability of the lithosphere. Regardless the mechanisms involved in its reworking, the incompatible element budget of this lithosphere is then dominated by the most voluminous, “enriched” crustal component ($\sim$2.95 Ga TTGs in that case). Models of early Earth evolution may therefore be reconsidered according to this alternative interpretation of Lu–Hf isotope arrays.