ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Lu–Hf isotopes: implications for understanding crustal evolution

by

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Knowledge of crustal evolution is important for understanding mineralization, because juvenile addition of material from the mantle into the crust is commonly associated with significant heat and fluid flow and element mobility. Geological Survey of Western Australia (GSWA) routinely determines the ages of rocks by measuring the ratios of uranium, thorium, and lead isotopes in crystals of zircon and other minerals using the Sensitive High Resolution Ion MicroProbe (SHRIMP). GSWA has added significant value to its regional geochronological U–Pb datasets by acquisition of complementary Lu–Hf data from previously dated crystals. The Lu–Hf analyses are conducted by the Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC) at Macquarie University. The project is funded through the Western Australian Government's Exploration Incentive Scheme (EIS) and aims to analyse up to 2000 crystals each year for four years. Lu–Hf analyses incorporate both detrital zircons in sedimentary rocks, as well as zircons from magmatic rocks, including those with multiple growth stages. This allows the reconstruction of crustal history at several points in time — all recovered from a single rock sample or, in some cases, from a single crystal.

The isotope ^{176}Lu is unstable and undergoes spontaneous β decay to stable ^{176}Hf, with a half-life of approximately 37 billion years. During melting, the daughter element hafnium (Hf) partitions into melts to a higher degree than the parent element Lutetium (Lu). This leads to significant variation in ^{176}Hf/^{177}Hf over time. Crystals with higher ^{176}Hf have evolved from a source with elevated Lu and **depleted** Hf (typically the radiogenic mafic residuum), whereas lower ^{176}Hf is a result of lower Lu and **enriched** Hf (typically the unradiogenic felsic melt). Juvenile addition from the mantle results in **depleted** Hf values at the time of zircon crystallization, whereas reworking of older crust produces **enriched** Hf values. Hence the Lu–Hf system can be used as a geochemical tracer, providing information on both the timing of material input into the crust as well as the process by which this material was added.

Owing to its close chemical affinity with zirconium, the element Hf is a significant component of zircon grains. Zircon has very low Lu/Hf ratios, which means that the Hf isotope composition measured today requires only a minor time-correction to derive the initial value at the time of crystallization. Moreover, zircon is physically and chemically robust and Lu–Hf isotopes are highly resistant to later disturbance (even more so than the U–Pb system), thus Lu–Hf in zircon has the potential to decipher the geological evolution of highly metamorphosed and overprinted terranes. When coupled with U–Pb geochronology, Hf isotope measurements in zircon provides unique, time-integrated information about the relative roles of juvenile mantle input versus reworking of older continental crust.

Lu–Hf results from the Albany–Fraser Orogen

The Albany–Fraser Orogen, along the southeastern margin of the Yilgarn Craton, represents the Mesoproterozoic continent–continent collision between the combined North and West Australian Cratons and the combined East Antarctic and South Australian Cratons (Bodorkos and Clark, 2004). However, recent geochronology, together with structural and geophysical data, reveals that the fault-bounded Paleoproterozoic Biranup Zone makes up a large component of the orogen, and includes rocks that were deformed during the c. 1680 Ma Zanthus event (Kirkland et al., in prep.). There has been considerable uncertainty regarding the origin of the Biranup Zone, with most work favoring an exotic source. However, Lu–Hf results indicate an indigenous origin on the Yilgarn margin. The oldest magmatic rocks in the Biranup Zone (c. 1700 Ma) have Hf isotope values similar to those of the Yilgarn Craton (Fig. 1). However, over about the next 50 million years, Hf isotopic values become increasingly dominated by more radiogenic (depleted) values (Fig. 1). This Hf evolution is compatible with melt production from mixed sources: a juvenile component, and an evolved component with crustal residence ages of more than about 3100 Ma. This juvenile material progressively and thoroughly diluted the isotope signal from the basement through time and reflects the influence of radiogenic Paleoproterozoic input into non-radiogenic Archean sources.

This temporal trend can also be recognized within individual intrusions. For example, magmatic zircon rims indicate higher εHf values than their cores, implying increasing juvenile input at a timescale below the age resolution of the geochronology. These results directly link the Biranup Zone

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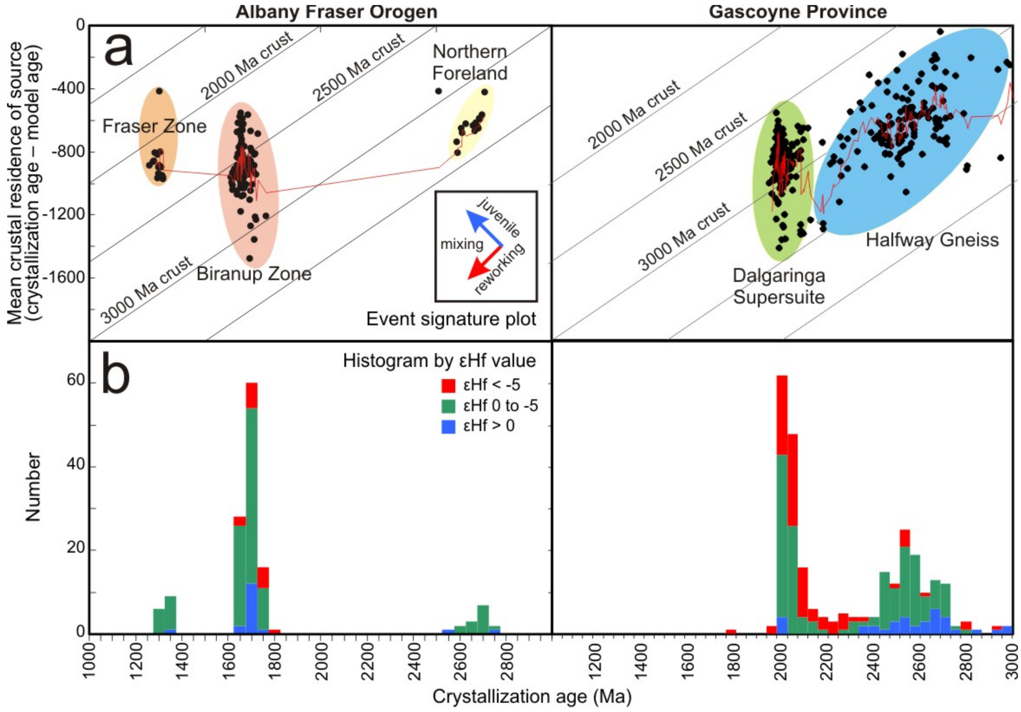

Figure 1. a) Event signature diagram showing the general trend of reworking (downwards), mixing (horizontal), or juvenile input (upwards); b) stacked histograms for juvenile (> 0), intermediate (0 to -5) and evolved (< -5) εHf values. The data on the left are from three lithostratigraphic domains in the Albany–Fraser Orogen: the Biranup Zone, Fraser Zone, and Northern Foreland. The data on the right are from the Gascoyne Province, Glenburgh Terrane

of the Albany–Fraser Orogen to the Yilgarn Craton margin, and suggest that the Paleoproterozoic evolution of the region is best explained by back-arc development and rifting on the craton margin between about 1700 and 1650 Ma. This process resulted in Archean remnants becoming isolated from their ancestral home on the Yilgarn Craton by additions of predominantly juvenile crust. This is important for clarifying the geodynamic setting of gold mineralization (such as the Tropicana deposit) on the southeastern Yilgarn Craton margin.

Lu–Hf results from the Gascoyne Province

The Capricorn Orogen records the Paleoproterozoic juxtaposition of the Archean Yilgarn and Pilbara Cratons to form the West Australian Craton (Johnson et al., 2010). The orogen consists of the deformed craton margins and a wedge of exotic rocks named the Glenburgh Terrane. The Glenburgh Terrane comprises a basement of heterogeneous granitic gneisses (the Halfway Gneiss), overlain by a package of continent-derived siliciclastic metasedimentary rocks (Moogie Metamorphics). These rocks were intruded at c. 2000 Ma by a suite of igneous rocks (Dalgaringa Supersuite), interpreted to have formed in a volcanic arc on the southern margin of the terrane prior to collision with the Yilgarn Craton (Sheppard et al., 2004). Hf isotopes from the Glenburgh Terrane imply a component of the terrane was resident in the crust since c. 3750 Ma, with additional crustal growth events at c. 2800–2600, 2600–2430, and 2005–1970 Ma (Fig. 1).

The oldest and youngest events appear to have tapped juvenile, mantle-derived material, whereas magmas generated in the 2600–2430 Ma episode were derived by the reworking of pre-existing crust. This crustal history is dissimilar to that of either the Pilbara and Yilgarn Cratons, confirming the exotic heritage of the Glenburgh Terrane prior to final suturing of the West Australian Craton during the Glenburgh Orogeny, between 2005 and 1950 Ma. Results for younger intrusions of the 1820–1775 Ma Moorarie Supersuite indicate mainly reworking of Glenburgh Terrane basement. However, some intermediate to felsic plutonic rocks of the Minnie Creek batholith are less evolved, suggesting mixing between mantle-derived material and pre-existing felsic crust. The evolution of the Gascoyne Province demonstrates the cyclic nature of crustal evolution, with episodic juvenile mantle additions into the crust, followed by major, prolonged reworking–homogenizing events.

References

Bodorkos, S and Clark, DJ 2004, Evolution of a crustal-scale transpressive shear zone in the Albany–Fraser Orogen, SW Australia: 2. Tectonic history of the Coramup Gneiss and a kinematic framework for Mesoproterozoic collision of the West Australian and Mawson cratons: Journal of Metamorphic Geology, v. 22, p. 713–731.

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh

Orogeny as a record of Paleoproterozoic continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Kirkland CL, Spaggiari CV, Pawley MJ, Wingate MTD, Smithies RH, Howard HM, Tyler IM, Belousova, EA and Poujol, M in prep., Paleoproterozoic tectonomagmatism and Mesoproterozoic reworking of the Albany–Fraser Orogen: U–Pb and Lu–Hf evidence for modification of the Yilgarn Craton margin: Precambrian Research.

Sheppard, S, Occhipinti, SA and Tyler, IM 2004, A 2005–1970 Ma Andean-type batholith in the southern Gascoyne Complex, Western Australia: Precambrian Research, v. 128, p. 257–277.