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Tracing granite-hosted mineralization via zircon metal anomalies

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Granite-hosted magmatic-hydrothermal mineral deposits are major sources of Cu, Mo, Sn, Li and W, originating via mineralizing fluids exsolved from volatile-saturated magmas. We show how trace elements in zircon sampled from the granite-hosted Zaaiplaats Tin Field, Bushveld Complex, South Africa, preserve a record of the enrichment of incompatible metals, both during magma fractionation, and from magmatic-hydrothermal mineralization processes.

Mineralization at Zaaiplaats resulted from closed-system magma differentiation and the eventual appearance of a saline magmatic Sn-rich hydrothermal fluid which promoted cassiterite precipitation in the central mineralized zone[1]. We sampled across the intrusion, covering the entire magmatic-hydrothermal paragenesis and, on the basis of mineralogy, subdivided samples into two groups: mineralized and unmineralized.

Unmineralized samples define a fractionation trend on the basis of zircon REE and HFSE arrays. Plots of Sm and Sn versus Gd show consistent trends, where Sn content is dominated by Rayleigh Fractionation. In contrast, the mineralized samples show an enrichment in Sn for the same degree of fractionation (i.e. Gd), which we attribute to the introduction of a Sn-rich mineralizing fluid resulting from volatile saturation during zircon growth and consistent with the preservation of whole-rock Sn zonation in the Zaaiplaats granites. Zircon Sn/Gd ratios from the unmineralized samples define a magma fractionation trend with increasing Y at constant Sn/Gd, whereas those from the mineralized samples are displaced to high Sn/Gd ratios at similar Y, a deviation marking the onset of mineralization processes.

A metal anomaly, Sn/Sn*, is defined[2] which describes the deviation of Sn over that expected through magma fractionation alone (Sn*), and arises from Sn mobilization due to magmatic-hydrothermal mineralization processes. Identification of metal anomalies such as Sn/Sn* or Cu/Cu* in mineral archives, or at the whole-rock level, provides an empirical link to the onset of mineralization processes in magmatic-hydrothermal systems, and can be coupled with geochemical proxies to yield a better understanding of the conditions leading up to, and subsequent to, volatile saturation.

[1] Groves and McCarthy (1978), *Mineralium Deposita* 13, 11-26.

[2] Gardiner et al. (2021), *Chemical Geology* 585, 120580.