Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.34584

Lithium release from Weardale granite during fluid-rock interaction: Implications for modern Li resources

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Lithium is a critical metal, and production is limited to a few countries, creating geopolitical tensions and raising concerns about the environmental impacts of conventional extraction. Developing new, unconventional Li resources, particularly geothermal brines in fractured granitic systems, offers a way to enhance energy security while supplying heat and metals. However, the geochemical processes that concentrate Li in these fluids remain poorly constrained. Key questions are whether Li is released from primary Li-bearing minerals during fluid-rock interaction, mobilised during ancient sub-aerial weathering, or introduced from external sources.

To address these questions, we applied multiple *in-situ* and bulk analytical techniques to the Weardale granite, northeast UK, a promising unconventional resource. Samples include minimally altered granite (WG1) and three altered varieties (WG-A1, WG-A2, and WG-A3). We mapped the major- and trace-element distribution in primary minerals and alteration products, in order to constrain the conditions and context of distinct alteration reactions and quantify element fluxes as the geothermal system evolves over time.

Mass-change calculations reveal contrasting Li trends. Bulk-rock Li enrichment (+ 0.94% Li) from WG1 to WG-A1 is driven by phengitisation of muscovite (+ 2500 ppm Li), indicating high-temperature greisenisation with fluids enriched in Li, Rb, Cs, Zn, Sn, and W. Conversely, bulk-rock Li-depletion from WG1 to WG-A2 (- 0.41 wt% Li) and WG1 to WG-A3 (- 0.51% Li) reflects two Li-mobilising reactions. Chloritisation of biotite in WG-A2 (-2000 ppm Li) occurred at > 300 °C and mobilised Li, Rb, Cs, Ba, and K into circulating fluids, while plagioclase concurrently underwent illitisation. Lower-temperature phengitisation of biotite in the pluton roof in WG-A3 (- 4500 ppm Li) caused the greatest Li loss. This is linked to lower-temperature feldspar illitisation and Pb, Ba, Sr enrichment, suggesting a burial-triggered hydrothermal event. Illite acts as a crucial Li mineral sink, with trace element chemistry showing it co-precipitated with phengite and chlorite. The distribution of secondary alteration products thus indicates zones of Li-rich fluid generation.

Future work will constrain the depth of Li-mobilising reactions via illite precipitation experiments, enabling assessment of whether similar alteration is presently releasing Li from granite, and help predict sustainability of Li resource.