

Alteration Controls on Lithium Distribution in Pegmatite Deposits: Geochemical Proxies for Exploration and Resource Evaluation

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Distinguishing economically viable lithium pegmatites from altered or depleted systems remains a major challenge in exploration and resource evaluation. Although the presence of spodumene is commonly used as a key exploration criterion, post-emplacement magmatic–hydrothermal and supergene processes can significantly modify or destroy primary lithium mineralization. Improved understanding of alteration controls on lithium preservation is therefore critical for accurate deposit characterization and targeting.

This study integrates petrographic observations, quantitative X-ray diffraction (QXRD), and geochemical analyses to evaluate alteration processes affecting spodumene-bearing pegmatites. Samples include surface outcrop and drill core material from the Musha–Ntunga pegmatite field (Rwanda), complemented by comparative material from Rwanda, the Democratic Republic of Congo, USA, Canada, China, and Zimbabwe. Twenty-eight spodumene mineral separates and corresponding host-matrix samples were analyzed using XRD, ICP-OES, and ICP-MS. The samples represent a spectrum of supergene weathering intensities and magmatic–hydrothermal alteration styles, including albitization and lepidolitization.

Lithium depletion in spodumene correlates with progressive alteration and is accompanied by systematic changes in trace-element distributions. Variations in rare earth elements (REE), Ge, Ga, and Ba show consistent relationships with alteration intensity and represent potential geochemical proxies that are less sensitive to primary mineralogical heterogeneity than lithium alone. Comparison between mineral separates and host matrices indicates that lithium mobilization during weathering is not necessarily accompanied by equivalent redistribution of certain trace elements, providing constraints on alteration pathways.

The proposed proxies were further evaluated using 2,440 drill core interval assays of spodumene-bearing pegmatites with variable weathering intensity. Statistical relationships confirm the reproducibility and regional applicability of REE, Ge, and Ba as indicators of alteration-driven lithium depletion.

These results provide practical geochemical tools for distinguishing preserved lithium mineralization from alteration-modified systems, with direct implications for exploration targeting, resource estimation, and mine planning.