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Apatite geochemistry as a tracer of Li–Cs–Ta pegmatite fertility

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Apatite provides a resilient geochemical archive capable of tracking lithium enrichment during pegmatite evolution and distinguishing Li–Cs–Ta–fertile systems from barren counterparts. We investigated major and trace element compositions of apatite from several Archean pegmatites of the Bird River greenstone belt (Manitoba, Canada) to evaluate its capacity to record Li mineralization processes. Apatite from Li-mineralized pegmatites is characterized by Mn enrichment, elevated Mn/Fe ratios, higher Li, U, and Th contents, low total REE abundances, reduced Eu_N values, and pronounced negative Eu anomalies with subtle tetrad effects, reflecting advanced melt fractionation and progressive volatile concentration linked to lithium saturation. In contrast, apatite from barren pegmatites displays higher ΣREE contents, higher Eu_N values, weaker Eu anomalies, and comparatively lower Mn/Fe and Li concentrations, consistent with less evolved melt conditions. Field and petrographic observations reinforce these geochemical distinctions: Li-mineralized pegmatites preferentially intrude mafic to intermediate host rocks, whereas those emplaced in felsic hosts are barren at current exposure levels. Accessory tantalite serves as an indicator of advanced rare-element fractionation, and pegmatites containing more than 15% K-feldspar represent comparatively less evolved systems. Overlapping emplacement ages (*ca.* 2655–2638 Ma) between fertile and barren pegmatites indicate that lithium fertility reflects internal melt evolution rather than timing of intrusion. These results demonstrate that apatite trace-element systematics provide a transferable mineral-scale framework for tracing lithium enrichment pathways and assessing rare-metal potential across crustal systems.