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The Enrichment of Lithium in Granites and Pegmatites: Insights from Mineral-Melt Partition Coefficients

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Rare-metal granites and pegmatites (RMGPs) are important ore deposits of lithium and other critical metals required for the global energy transition. Despite their economic significance, the petrogenesis of these deposits remains widely debated in the literature. The two competing metallogenic models of RMGPs include either the crystallization of highly differentiated felsic melts or the low-degree partial melting of metasedimentary rocks. The degree of lithium enrichment during these processes is typically modelled by using mineral-melt partition coefficients ($D^{Mineral/Melt}$) and the modal mineralogy of crystallizing or melting assemblages. Partition coefficients are often derived from natural systems; however, the resulting $D^{Mineral/Melt}$ may vary by over two orders of magnitude due to the overprinting of plutonic and volcanic chemical signatures following emplacement. Experimental $D^{Mineral/Melt}$ are scarce and also vary significantly as a function of crystallization and melting conditions. Thus, interpretations of RMGP metallogenic models may differ dramatically, depending on the $D^{Mineral/Melt}$ used to calculate lithium enrichment during magmatic processes. In order to better constrain the distribution of lithium during anatexis and fractionation, partial melting and crystallization experiments were performed on metasediments and felsic glasses, respectively. Mineral-melt partition coefficients were determined for common granitic and metamorphic minerals, including micas, feldspars, quartz, staurolite, cordierite, garnet, and tourmaline. The experimental results demonstrate that $D^{Mineral/Melt}$ varies primarily as a function of mineral and melt compositions, as well as the temperature of the system. The newly constrained partition coefficients were subsequently used to perform step-wise trace element modelling of crustal anatexis and fractional crystallization. The evolving composition of minerals and melts were modelled using Perple_X and MELTS, which was used as a proxy to incrementally vary $D^{Mineral/Melt}$. The modelled results are consistent with economic-grade granite and pegmatite deposits (>5000 ppm lithium) forming in a two-stage process. The anatexis of enriched metasediments (~300-500 ppm lithium) produces partial melts with up to 3000 ppm lithium, which become further enriched by moderate fractional crystallization to produce RMGPs. Alternative genetic models are further explored, which all highlight the significance of an enriched crustal source.