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Source-to-sink enrichment of lithium in granitic pegmatites

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Lithium is a high-demand critical metal that is primarily sourced from economically important granitic pegmatites. Precise constraints on the formation of lithium-rich granitic pegmatites are thus essential to improve exploration prospects for new ore deposits. Lithium can become enriched in pegmatite-forming melts during crustal anatexis and fractional crystallization, which can be modelled using mineral-melt partition coefficients and the modal mineralogy of melting or crystallizing assemblages. Evolving mineral assemblages during anatexis and fractionation are typically determined using thermodynamic models; however, these do not account for the effect of lithium, and other fluxing elements (F, P, and B), which have a drastic effect on phase stability and the temperature of melting or crystallization. Furthermore, the validity of petrogenetic models relies on the accuracy of mineral-melt partition coefficients. However, the use of highly variable partition coefficients available in the literature results in strikingly different and contrasting interpretations of lithium enrichment during magmatic differentiation. To better understand the petrogenesis of lithium-rich granitic pegmatites, step-wise trace element modelling was performed using new mineral-melt partition coefficients, constrained by partial melting and crystallization experiments. The enrichment of lithium during crustal anatexis and fractional crystallization was simulated by incrementally varying partition coefficients to capture the evolution of mineral and melt compositions as a function of temperature and pressure. The modal mineralogy of melting and crystallizing assemblages was determined using a combination of thermodynamic models (Perple_X and MELTS) and empirical equations, constrained using available experimental data on phase stability in flux-rich, felsic systems. The modelled results are consistent with economic-grade granitic pegmatites (> 5000 ppm lithium) forming in a two-stage process. Lithium enrichment in pegmatite-forming melts begins with the anatexis of an enriched crustal source (> 300 ppm lithium). The pre-enrichment of lithium in the anatectic melts lowers the liquidus of the system, which in turn is concomitant with lithium becoming increasingly incompatible in granitic minerals at a low temperature. The combined effect of pre-enrichment on the liquidus and the partitioning behavior of lithium induces a runaway effect, wherein extracted melts can become efficiently enriched during protracted fractional crystallization to produce economic-grade pegmatite deposits.