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A recipe for anatectic lithium-rich pegmatites: partial melting and in-source fractionation

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Lithium-cesium-tantalum (LCT) pegmatites, which account for half of the world's production of lithium are formed by extreme fractionation of parental peraluminous granitic intrusions or low degrees of partial melting of crustal lithologies. However, the processes behind the formation of economic deposits remain poorly understood, particularly concerning metal enrichment during crustal anatexis.

Field and Sr-Nd isotope evidence indicate that LCT pegmatites in the thermal aureole of the Adamello pluton (Italy) formed by low-pressure partial melting of Al-rich clastic rocks with Li contents <80 ppm. These pegmatites, which form small, zoned dikes, represent an ideal natural laboratory for investigating the processes that produce anatectic hard-rock deposits of lithium and other critical rare metals. The limited size of the mineralized bodies, combined with our strategy of composite sampling, has allowed us to determine the overall whole-rock composition of the pegmatites and their internal chemical variability. The pegmatites are peraluminous, high-silica rocks (SiO_2 = 78 wt%) with a K_2O/Na_2O of 0.6 and a Li content of 550 ppm. Internally, the Li content varies from 50 ppm in the border zone to up to 1150 ppm in the core, where it is hosted in Li-rich micas (lepidolite and zinnwaldite) and elbaite.

In this study, we combined phase equilibria modelling with trace element geochemical modelling. Our simulations demonstrate that fluid-limited melting produces a relatively small amount of Li-enriched granitic melt at temperatures below 800°C only when limited amounts of peritectic cordierite are formed. However, the calculated lithium content of the melt is only three to five times higher than the lithium concentration in the protolith, suggesting that partial melting alone is not sufficient to produce the lithium content of the studied pegmatites. The migmatites of the thermal aureole host K-feldspar-rich leucogranitic veins, which we interpret as K-feldspar cumulate rocks. Based on chemical arguments, we propose that low percentages of in-source fractional crystallization of K-feldspar during melt extraction contribute to the formation of Li-enriched pegmatites. Our case study demonstrates that only modest Lithium enrichment can be achieved during anatexis, thus supporting the idea that the formation of this type of deposits requires partial melting of Li-enriched sources.