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Formation of giant pegmatitic lithium deposits by phase separation of supercritical magmatic fluids

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Deciphering the petrogenesis of Li-mineralized pegmatites is essential to unravel rare metal enrichment mechanisms, yet the role of magmatic-hydrothermal fluids in lithium enrichment within LCT (Li-Cs-Ta) systems remains debated. To address this, we present K isotope data for scientific drilling cores and surface samples in the Jiajika pegmatite field, which hosts the largest hard rock-type Li deposit in Asia. Our results reveal that pegmatites exhibit significantly $\delta^{41}K$ variability (−1.23‰ to −0.22‰) compared to two-mica granites (−0.68‰ to −0.47‰) and aplites (−0.69‰ to −0.60‰). Strikingly, Li-mineralized pegmatites display the lightest $\delta^{41}K$ values (−1.23‰ to −0.58‰), correlating strongly with indicators of fluid activity (e.g., Zr/Hf, $TE_{1,3}$ ratios). These trends reject crustal anatexis or feldspar-dominated fractional crystallization, instead implicating the involvement of isotopically light K magmatic fluids during late-stage magmatic evolution. The progressive $\delta^{41}K$ depletion observed from granites to pegmatites reflects fluid−melt interaction during magmatic−hydrothermal transition, amplified by phase separation. Supercritical fluids exsolved from highly crystalline magmatic reservoirs efficiently transported lithium, while rapid decompression via dome-related fissures facilitated fluid exsolution and migration, ultimately driving pegmatite stratification and spodumene precipitation. This study suggests K isotopes as a robust tracer of magmatic fluid behavior, establishing a petrogenetic linkage between Li mineralization and magmatic-hydrothermal processes. These insights advance exploration strategies for LCT pegmatites by prioritizing settings conducive to phase segregation, such as gneiss dome-related fissures.