

Unravelling the magmatic-hydrothermal genesis of Li-rich pegmatites using apatite geochemistry

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Lithium-bearing pegmatites are the primary source of battery-grade lithium [1]. They form from the crystallisation of highly evolved, volatile- and metal-rich magmas. The unique composition of pegmatite melts promotes a complex paragenesis during crystallisation resulting in internal zoning, and involving the transition from a magma-dominated to a fluid-dominated system, yet the timing of volatile saturation with respect to melt evolution and metal concentration remains debated.

Initially, petrogenetic models suggested that pegmatite melts were volatile-saturated, crystallising in the presence of an exsolved fluid phase [2]. However, experimental models indicate pegmatites crystallise as fluid-undersaturated systems [3] with volatile saturation occurring late in the crystallisation sequence, whereas fluid inclusions studies suggest that pegmatites crystallise from a melt-melt-fluid system [4].

Apatite is a common accessory mineral whose volatile and trace element compositions have been utilised to constrain fluid and melt evolution in a wide range of magmatic systems, although less commonly applied to granite-hosted mineralisation systems. Here, we use apatite volatile and trace element compositions coupled with thermodynamic modelling, to inform on pegmatite crystallization and associated, melt-metal evolution, including the timing of the magmatic-hydrothermal transition with an in-depth study of the Arcadia Li pegmatite field in Zimbabwe.

Apatite chemistry shows that Arcadia Li-bearing pegmatite melts evolved as water-saturated systems actively exsolving fluids with ongoing fractionation, implying that the magmatic-hydrothermal “transition” may instead be a continuous process occurring early in the crystallisation sequence, and not a discrete event. The exsolved fluid was not necessarily expelled but remained within the system, auto-metasomatizing primary phases, introducing complexity to Li ore mineral paragenesis. Additionally, apatite sampled from the aplitic and albitite-Li ore zones reveals two compositional pathways, with different volatile budgets, supporting the hypothesis of a melt-melt-fluid system.

[1] Gardiner, N. J., et al. (2024) *Geoenergy*, 2: 1-6.

[2] Jahns, R. H., et al. (1969) *Economic Geology*, 64: 843-864.

[3] London, D., et al. (1989) *Contributions to Mineralogy and Petrology*, 102: 1-17.

[4] Thomas, R., et al. (2016) *Ore Geology Reviews*, 72: 1088-1101.