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Modelling trace element evolution in arc magmas: implications for interpreting copper porphyry indicators

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Trace element ratios in arc magmas are widely used to infer petrogenetic conditions, particularly those associated with porphyry-forming versus barren systems [1]. For example, high Sr/Y and listric rare-earth element (REE) profiles in copper-mineralised arc magmas have been attributed to extensive amphibole (+/- garnet) fractionation and suppressed plagioclase. These mineral assemblages are linked to lower crustal crystallisation of hydrous magmas [e.g. 2,3]. However, quantitatively linking whole-rock signatures to pressure, water content, and/or redox conditions remains challenging, as trace elements are sensitive to mineral assemblage and compositions, which both evolve during fractional crystallisation. While experiments provide insights into assemblages at selected conditions [e.g. 4], commonly used forward-modelling tools are unsuitable for amphibole-bearing arc magmas. Here, we integrate a recently updated thermodynamic model suite appropriate for arc systems [5] with dynamic (composition-, temperature-dependent) mineral-melt partitioning to track trace element evolution. Benchmarking the model against published experiments, including apatite saturation, shows that the methodology successfully reproduces phase assemblages and compositions [6].

We simulate fractional crystallisation of an average primitive arc magma across mid- to lower-crustal pressures (4–10 kbar), 2–4 wt% initial H_2O, and a range of redox conditions (~2 log units ΔFMQ). We demonstrate how mineral-specific vectors evolve in trace element ratio (e.g. Sr/Y, Dy/Dy*) and rare-earth element shape coefficient (λ) space. Results highlight that amphibole and garnet crystallisation may produce overlapping λ-vectors under deep, hydrous conditions—contrary to orthogonal vectors inferred using static (composition-, temperature-independent) partitioning. Multiple petrogenetic paths can also yield similar whole-rock trace element outcomes. High Sr/Y, for example, commonly associated with porphyry systems, can form without particularly deep or hydrous conditions when dynamic partitioning behaviour is considered, if extensive fractionation can occur [6]. Overall, our modelling framework enables evaluation of arc magma petrogenesis and trace element evolution, including indicators of Cu porphyry fertility.

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