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Amphibole-rich cumulate xenoliths in the Zhazhalong intrusive suite, Gangdese arc: Implications for the role of amphibole fractionation during magma evolution

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Abstract

Amphibole fractionation during the early evolution of arc magmas has been widely inferred on the basis of distinctive geochemical fingerprints of the evolved melts, although amphibole is rarely found as a major mineral phase in arc volcanic rocks, so-called cryptic amphibole fractionation. Here, we present a detailed case study of xenoliths of amphibole-rich cumulate from the Zhazhalong intrusive suite, Gangdese arc, which enables an investigation of this differentiation process using a combination of petrological observations and in situ geochemical constraints. Evidence that the xenoliths represent fragments of igneous cumulates includes: (1) the presence of an amphibole-dominated crystal framework; (2) mineral and whole-rock Fe–Mg exchange coefficients; (3) rare-earth element patterns that are similar in the amphiboles and the xenoliths; (4) the compositions of basaltic to andesitic liquids in equilibrium with amphiboles; and (5) enrichment of the xenoliths in compatible elements and depletion in incompatible elements. The amount of trapped liquid based on La, Ce, and Dy abundances varies from ~12 to ~20%. Actinolitic cores within amphibole grains likely represent reaction between olivine precursor and hydrous melt, as evidenced by their high Cr and Ni contents. Amphibole thermometry and oxybarometry calculations indicate that crystal accumulation occurred over temperatures of 857–1014 °C, at mid-crustal pressures of 312 to 692 MPa and oxygen fugacity between 0.4 and 1.9 log units above the nickel–nickel oxide buffer. Quantification of the major-element compositions of the parent liquids indicates that the Zhazhalong amphibole cumulates crystallized from basaltic to andesitic magmas, probably with a shoshonitic affinity, and with SiO_2 contents of 46.4–66.4 wt%. Appropriate partition coefficients, calculated using a parameterized lattice strain model and an empirical partitioning scheme, were employed to calculate the trace-element compositions of the liquids in equilibrium with amphibole. Our results confirm that Dy/Yb and Dy/Dy* ratios, which decrease with increasing degrees of differentiation, can be used as robust signatures of amphibole fractionation. This work presents a direct snapshot of the process of amphibole fractionation and provides a natural example of the hidden amphibole "sponge" in arc crust. In particular, this study also suggests that some appinites likely represent amphibole-rich cumulates, which may help to explain the genesis of other unusual but petrologically significant rocks.

Keywords: Amphibole, fractional crystallization, cumulate, magma evolution, trace element