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 SiO2 contents of 46.4–66.4 wt%. Appropriate partition coefficients, calculated using a parameterized lattice strain model and an empirically determined 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

INTRODUCTION

Arc magmatism at subduction zones represents the sites of production of new continental crust (Rudnick 1995). There is a little dispute that primitive arc magmas are generated by partial melting in the mantle wedge in response to the dehydration of down-going slabs (e.g., Tatsumi 1989; Hawkesworth et al. 1993; Ulmer and Trommsdorff 1995; Grove et al. 2002). However, few of these mantle-derived magmas reach the surface without significant modification. Various processes have been proposed to explain the origin of evolved magmas. Remelting of the preexisting crust is commonly invoked in the petrogenesis of granitoid plutons (e.g., Chappell and White 1992; Clemens and Stevens 2012; Brown 2013), and there is compelling evidence for a genetic link between metasedimentary rocks and strongly peraluminous granites (Chappell and White 1992). Crustal melting is efficient where heat is supplied by underplating mafic magmas (e.g., Pettford et al. 2000). Thus, partial melting of the crust is sometimes regarded as a concomitant process in deep-crustal hot zones, where fractional crystallization of mantle-derived basaltic parents, partial melting of the surrounding crust, and hybridization of residual and crustal melts occur simultaneously (Hildreth and Mooibath 1988; Annen et al. 2006).

Over the past decade, a growing number of studies have supported fractional crystallization of hydrous basaltic magmas as the dominant process responsible for the production of intermediate and silicic magmas (e.g., Lee and Bachmann 2014; Jagoutz and Klein 2018). Experimental results suggest that the origin of compositional diversity in magmas can be attributed mainly to fractional crystallization (e.g., Grove and Brown 2018; Müntener and Ulmer 2018). Field observations and detailed studies of natural rock