Magma mush chemistry at subduction zones, revealed by new melt major element inversion from calcic amphiboles

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\textbf{ABSTRACT}

We have used multiple-regression methods to calibrate new, pressure-independent empirical chemometric equations to calculate the major element composition of basanitic to rhyolitic melts in equilibrium with calcic amphibole. The equations are based on amphibole stoichiometric formula components ± temperature from published experimental P-T-X data and avoid some problems of previous studies associated with uncertainties in pressure determination. Compared with the pressure-dependent equations of Ridolfi and Renzulli (2012), tests run using an independent data set indicate that the new equations yield improved precision and accuracy, in particular for SiO\textsubscript{2}, TiO\textsubscript{2}, CaO, and K\textsubscript{2}O. The results are only marginally more precise when temperature is used as a dependent variable, demonstrating that temperature has a relatively minor role in controlling amphibole crystal chemistry compared with melt composition. This allows us to accept a small decrease in precision in excluding temperature from the analysis, which is very convenient for application of the equations to natural amphiboles where temperature is typically unknown.

Using the new chemometric equations, reconstructed melt compositions in equilibrium with the rims of amphiboles in pumice clasts of the Ongatiti ignimbrite are in good agreement with coexisting matrix glass compositions, lending support for our analysis. The compositionally variable cores of the amphiboles give predicted melt compositions with large compositional variations from andesitic (63 wt% SiO\textsubscript{2}) to high-Si rhyolite. These compositional variations in the predicted melt compositions suggest that there may be a range of heterogeneous melts undergoing progressive differentiation within a major crustal magma storage region underneath the volcano. The results support the existence of genuine intermediate composition melts within the storage region. Interaction between these stored melts, disaggregating mush fragments and replenishing magmas gives rise to the chemical complexity observed in erupted magmas. We also used our multiple regression model to predict the compositions of melts that were in equilibrium with amphiboles in plutonic nodules from Grenada lavas. The predicted melts cover a wide range of compositions, perhaps as a result of in situ fractionation, but are consistent with melt inclusions hosted in those cumulates, as reported by Stamper et al. (2014). Overall, our new pressure- and temperature-independent equations resolve issues associated with previous pressure-dependent studies and represent a useful tool for further investigation of crustal processes at subduction zones.

\textbf{Keywords:} Calcic amphibole, chemometrics, melt compositions, multiple regression, Ongatiti ignimbrite, plutonic xenoliths, Grenada

\textbf{INTRODUCTION}

Amphibole is a common, but chemically complex mineral phase present in many hydrous arc magmas. Experimental studies show that amphibole crystallizes over a large range of pressure and temperature from diverse melts of basanitic to rhyolitic composition (see below; Fig. 1). The crystal chemistry of amphibole is sensitive to various magma intensive variables (e.g., pressure, temperature, oxygen fugacity \textit{f}\textsubscript{O2}), as well as melt composition and volatile content (e.g., Ridolfi and Renzulli 2012; Ridolfi et al. 2008, 2010). Because of its broad stability range, amphibole has long been used for thermobarometry (e.g., Anderson and Smith 1995; Blundy and Cashman 2008; Blundy and Holland 1990; Ernst and Liu 1998; Hammarstrom and Zen 1986; Holland and Blundy 1994; Hollister et al. 1987; Krawczynski et al. 2012; Molina et al. 2015; Putirka 2008, 2016; Ridolfi and Renzulli 2012; Ridolfi et al. 2010; Schmidt 1992). To begin with, amphibole-related barometers were mainly based on the presence of a low-variance equilibrium assemblage. For example, the Al-in-hornblende barometer requires the assemblage quartz + K-feldspar + plagioclase + hornblende + biotite + Fe-Ti oxides + titanite + melt + fluid (e.g., Anderson and Smith 1995; Hammarstrom and Zen 1986; Hollister et al. 1987). More recently, empirical amphibole-only thermobarometers have been