MELT-FLUID INCLUSIONS AND VOLCANIC PROCESSES

Quantitative models linking igneous amphibole composition with magma Cl and OH content†

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ABSTRACT

Minerals of the amphibole group are found in igneous rocks on Earth and other rocky bodies. Since the O(3) site of amphibole can contain OH, O^{2-}, F, and Cl, amphibole composition provides important information about water and halogen contents, oxidation state, and other features of its formation and alteration environments. However, the complexity of amphibole crystal chemistry means this information is difficult to extract. Furthermore, it has been regular practice in the era of the electron microprobe to neglect H and Fe^{3+} analyses for amphibole, critically reducing the amount of information available in amphibole analyses in the literature.

We have assembled models and insights from previous work to create a methodology that allows the estimation of magmatic H_2O and Cl contents from existing amphibole analyses. Since the methodology requires use of a cation norm, we begin with a deeper investigation of the consequences of different cation normalization schemes for amphibole analyses, and provide grounds for deciding which scheme best fits a given amphibole analysis. We then show how the existing model of Popp and coworkers can be reversed to estimate the OH and $^{[O(3)]}O^{2-}$ contents of amphiboles in synthesis experiments. Using a synthetic data set collected from the literature (39 amphibole analyses), we calibrate a partitioning model for the OH/Cl competition on the O(3) site of igneous amphiboles

$$K_{Cl} = (X_{Cl}/X_{OH})_{amphibole}/([Cl]/[OH])_{melt}$$

$$\ln K_{Cl} = 6.59 \, K/(Na + {}^{[A]}\square) - 0.679 \, Mg + 0.487 \, {}^{[6]}Fe$$

where X signifies a mole fraction of an anion on the O(3) site; [Cl] and [OH] signify melt mole fractions of the anion in question on a one-oxygen (Stolper-Zhang) basis; K, Na, $^{[A]}\square$, Mg, and $^{[6]}Fe$ signify the amount of each component in the amphibole in atoms per amphibole formula unit, with $^{[A]}\square$ denoting vacancies on the amphibole A site.

We then combine the Popp et al. model with our new model to link the occupancy of the amphibole O(3) site and other crystal chemical parameters to the Cl and H_2O content of melts crystallizing amphibole. The competition between OH and Cl for this site can be used to calculate the melt and amphibole OH/H_2O contents, as well as the speciation of Fe in amphibole, provided that the Cl content of both the amphibole and its coexisting melt is known, without analyzing either phase for H or Fe^{3+}/Fe^{2+}.

While the models in this paper should be recalibrated using future experimental data, this work shows that considerably more information about the volatile contents of magmas can be gleaned from amphibole than previously shown and provides additional information about the crystal chemistry of amphibole and how it affects Cl partitioning into minerals of this group.

Keywords: Amphibole, mineral/melt partitioning, chlorine, water, igneous petrology