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Temperature-induced Al-zoning in hornblendes of the Fish Canyon magma, Colorado

OLIVIER BACHMANN* AND MICHAEL A. DUNGAN

Section des Sciences de la Terre de l'Université de Genève, 13, Rue des Maraîchers, 1211 GENEVE 4, Switzerland

ABSTRACT

An extensive electron microprobe survey of amphibole compositions in the Fish Canyon magma (2146 analyses), more than 80% of which are from high-resolution (<10 μm steps) core-to-rim traverses across large euhedral phenocrysts, provides: (1) temporal constraints on the immediately pre-eruptive P-T-f_{H_2O} evolution of the magma, and (2) a means of evaluating recent calibrations of the Al-in-hornblende barometer (Anderson and Smith 1995; hereafter AS1995) and thermometers (Blundy and Holland 1990; thermometers A and B of Holland and Blundy 1994; hereafter BH1990, HB1994TA, and HB1994TB).

Hornblende phenocrysts are variable for most major elements (e.g., 5–9 wt% Al_2O_3 and 44–50 wt% SiO_2). This compositional range is controlled by two major temperature-sensitive coupled substitutions. Approximately 50% of the total Al variation (~0.8 atoms per formula unit = apfu) is due to the edenite exchange [$^{T}Si + {}^{A}\square = {}^{T}Al + {}^{A}(Na + K)$] and another 25–30% is the consequence of a Ti-Tschermak exchange ($^{T}Si + {}^{M1-M3}Mn = {}^{T}Al + {}^{M1-M3}Ti$). In contrast, the pressure-sensitive Al-Tschermak substitution ($^{T}Si + {}^{M1-M3}Mg = {}^{T}Al + {}^{M1-M3}Al$) did not play a significant role, as $^{M1-M3}Al$ does not correlate with ^{T}Al and is always <0.2 apfu.

In order to constrain the ranges of absolute P and T over which these hornblendes crystallized and to assess the sensitivity of the recent thermo-barometric algorithms of BH1990, HB1994TA (requiring silica saturation), HB1994TB (not requiring silica saturation) and AS1995, we have calculated pressures and temperatures for two selected populations of analyses wherein Al_2O_3 contents are within analytical error (5.95 to 6.05 wt% Al_2O_3, N = 78 and 7.7 to 7.8 wt% Al_2O_3, N = 40). The barometric formulation of AS1995 gives a mean pressure of 2.24 ± 0.05 for the high-Al population at 760 °C, which is indistinguishable from the 2.4 ± 0.5 kbar estimate of Johnson and Rutherford (1989a). A high sensitivity to temperature at low P is suggested by the geologically implausibly shallow depths calculated for the low-Al population (<1 kbar at 760 °C). The three thermometric formulations give reasonable results between 706 and 814 °C, but the HB1994TA calibration gives a mean temperature higher by ~50 °C and is more sensitive to small analytical differences (~100 °C spread for each population). HB1994TB is considered the most reliable calibration of the Al-in-hornblende thermometer as it most precisely reproduces T estimates determined by independent methods.

Nine out of 14 traverses across large phenocrysts from the Fish Canyon magma display rimward increases in ^{T}Al, $^{A}(Na + K)$, and $^{M1-M3}Ti$, compensated by decreases in ^{T}Si, and $^{M1-M3}Mn$. Using the HB1994TB algorithm, the low-Al population, typical of near-core compositions, gives a mean temperature of ~715 °C, which is ~35–45 °C above the water-saturated granite solidus at 2–2.5 kbar. The high-Al population, representing the average rim composition, gives a value around 760 °C, which is indistinguishable from independent T determinations using coexisting Fe-Ti oxides and Qtz-Mag oxygen isotope thermometry. These profiles suggest that Fish Canyon hornblendes crystallized during near-isobaric reheating over a temperature range of ~40 °C, which is consistent with our model of rejuvenation and remobilization of a pre-existing near-solidus crystal mush of batholithic dimensions via shallow intrusion of more mafic magma (Bachmann et al. 2002). Crystallization of hornblende from a high-SiO_2, low-MgO melt during reheating requires an open system, in which both heat and mass, in particular volatiles, are transferred from the underlying mafic magma.

INTRODUCTION

and its initial calibration on the basis of P estimates derived