

Geochemical variation in biotite from the Devonian South Mountain Batholith, Nova Scotia: Constraints on emplacement pressure, temperature, magma redox state and the development of a magmatic vapor phase (MVP)

JAMES M. BRENNAN^{1,*†}, BRYAN J. MACIAG^{1,‡}, AND JACOB J. HANLEY²

¹Department of Earth and Environmental Sciences, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada

²Department of Geology, Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada

ABSTRACT

Here we report the composition of biotite from the peraluminous Devonian South Mountain Batholith (SMB) of southwestern Nova Scotia (Canada), the largest intrusive body within the Appalachian orogen. The batholith was emplaced in two phases: an early (379–375 Ma) granodiorite-monzogranite suite (Stage 1) and a later (375–372 Ma) more-evolved monzogranite-leucogranite suite (Stage 2). Biotite analyses (major and minor elements) were obtained on 55 unmineralized samples representing 11 plutons. Regardless of the stage of pluton emplacement, biotite is commonly interstitial to alkali feldspar, quartz and plagioclase, indicating similar timing of biotite saturation. This suggests that biotite chemistry records conditions at similar extents of magma evolution for the chosen suite of samples. Biotite compositions are Fe-rich, with Fe/(Fe+Mg) ranging from 0.6 to 0.98, and Al-rich, with ^{IV}Al ranging from 2.2 to 2.9 atoms per formula unit (apfu; 22 oxygen basis), the latter reflecting the coexistence of other Al-rich phases, such as muscovite, garnet, aluminosilicates, and cordierite. Biotite anion sites are dominated by OH (>3 apfu), followed by F (~0.3 apfu) and Cl (≤0.02 apfu), with a general trend of decreasing OH, increasing F and a marked decrease in Cl, with increasing differentiation.

Pressure (*P*) is estimated from the Al content of biotite to be between 280–430 MPa, consistent with a range of 240 to <470 MPa derived from phase equilibria and fluid inclusion microthermometry combined with mineral thermobarometry. Temperature (*T*) calculated from the Ti content of biotite ranges from 603–722 °C. Comparison of *P-T* estimates with water-saturated granite phase relations suggest minimum water contents of 6–7 wt% for the SMB magmas. The redox state of the SMB was estimated by comparing biotite Fe#-Ti relations with compositions calculated using the MELTS thermodynamic model, as experiments have shown that biotite Fe# increases with decreasing *f*_{O₂} at a given extent of crystallization. Results of MELTS modeling for the most primitive magmas of the SMB sample suite indicate that the observed biotite Fe#-Ti variation is consistent with crystallization at FMQ to FMQ-1, with more oxidizing conditions suggested for the most strongly differentiated samples.

To constrain the origin of the biotite anion site variation, a quantitative model using biotite-melt exchange coefficients (*K_b*) derived from existing experimental data was used to track the change in biotite OH-F-Cl abundances as a function of crystallization, with or without an extant magmatic vapor phase (MVP). The model reproduces the relative OH, F, and Cl abundances in biotite, and suggests that SMB crystallization occurred in the presence of a MVP. The relatively reduced redox state of the SMB, similar to other peraluminous granitoid occurrences worldwide, aligns with other measures of *f*_{O₂} for the SMB, including the occurrence of primary ilmenite. The observed correspondence between the estimated *f*_{O₂} and that imposed by graphite-gas equilibrium suggests a role for reduced carbon in the generation and evolution of the SMB. This is consistent with evidence for SMB interaction with graphite-bearing felsic granulites of the underthrust Avalon terrane, and assimilation of carbonaceous and sulfidic metasediments during pluton ascent and emplacement.

Reducing conditions and development of a MVP have implications for granophile element concentration processes in the SMB magmatic system. Low *f*_{O₂} during crystallization affects the mineral/melt partitioning and solubility of the redox-sensitive elements Sn, W, U, and Mo, serving to suppress early SnO₂ precipitation, and cause both an increase in W/Mo and an overall buildup of all four elements in evolving SMB liquids. Available experimental data indicate that reducing conditions also shifts *D*^{MVP/melt} to favor partitioning into the melt phase. Therefore, early vapor exsolution under reducing conditions also lessens the extraction efficiency of these redox-sensitive elements to the MVP, further underscoring the role of extensive crystallization as an important metal enrichment process.

Keywords: Biotite, halogens, peraluminous granite, South Mountain Batholith, oxygen fugacity; Experimental Halogens in Honor of Jim Webster