Wet or Oxidizing? Deciphering the Dominant Determinant of Calc-Alkaline Differentiation using a Monte Carlo MELTS Methodology

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Although calc-alkaline (CA) differentiation trends are ubiquitously assosiated with subduction zones, many arcs, and even single arc volcanoes, also erupt tholeiitic (TH) magmas. Furthermore, CA magmas have also been reported in Iceland and several continental rift settings. While experiments suggest a correlation between high H_2O and CA differentiation, few studies have assessed the specific role of fO_2, independent of H_2O. Thus, the relative importance of oxidizing vs. hydrous conditions has not been established. Furthermore, the time-consuming nature of such experiments has also inhibited investigation of the sensitivity of these liquid lines of descent (LLDs) to small changes in intensive parameters (e.g. H_2O, fO_2, P, parent composition) over a wide range of values.

To address this fundemental petrologic question, we took a Monte Carlo approach, using MELTS to model LLDs starting with seven parental compositions from four magmatic systems (Thingmuli, Iceland; Newberry, Oregon; Seguam and Augustine, Alaska). For each parental composition, we completed ~2,000 MELTS runs, each with a different constrained fO_2 (FMQ-1 to FMQ+3), initial H_2O (0.1 - 6 wt. %), and P (100 - 500 MPa, isobaric). We calculate the multivariate sum of squared differences (SSD), which quantifies the fit of each modeled LLD to observed data, and calculate the tholeiitic index (THI) to quantify Fe-enrichment. This allows us to plot, for each P, a 3-D surface of both SSD and THI as a function of H_2O and fO_2 and to assess, with unprecedented precision, the effect of various intensive parameters on differentiation pathways of magmas.

We find that the fit of modeled LLDs to observed data for all systems (CA and TH) are highly sensitive to small changes in both fO_2 and H_2O, and the relative role of each parameter is affected by both P and parent composition. Importantly, we demonstrate that under oxidized conditions (FMQ > 0.5), magma will evolve along a CA differetion trend, regardless of H_2O content or parental composition. This suggests that the juxtoposition of CA and TH compositions observed in arcs worldwide may be the result of different oxidative conditions during differentiation rather than distinct mantle sources or variable H_2O contributions from the subducting slab.