Systematic geochemical variations in single eruptions of primitive basalts: Tectonic implications

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Basalt geochemical variations over 10^1-10^3 km length scales or Myr time scales are often used to interpret large-scale tectonic processes. Major element variations over 10^2 km scales, for example, have been used to model asthenospheric upwelling and lithospheric depths in the western U.S. In addition, isotopic and trace element shifts over Myr timescales have been used to suggest shifts from lithospheric to asthenospheric sources during slab rollback. These approaches implicitly assume that basalt chemical variations on much shorter time and length scales are either small or irrelevant to larger scale trends and their tectonic controls. However, if chemical variations of similar style and magnitude were observed within single eruptions, they would be difficult if not impossible to attribute to large-scale tectonic processes, and thus would raise questions about such interpretations.

Here we show an example of systematic, large-magnitude, temporal-compositional trends in a single monogenetic eruption of primitive basalts erupted over a 10^0-10^2 yr timescale in the Big Pine Volcanic Field of southern CA. This eruption produced basalts with a high and constant Mg# of 69±1, decreasing (by a factor-of-two) incompatible element concentrations, increasing SiO_2 from 45 to 48 wt.%, decreasing $^{87}Sr/^{86}Sr$ from 0.7063 to 7055, and increasing ε_{Nd} from -3.5 to -1.0. REE patterns require residual garnet in at least one source. These trends cannot be due to fractional crystallization or partial melting of a single source, and crustal contamination models are difficult to reconcile with nearly constant, high Mg#, small Ni and Cr variations, inverse correlations between SiO_2 and incompatible elements, and the presence of abundant mantle xenoliths.

If interpreted in terms of pressures of melting variations such as might be caused by lithospheric thickness variations, these chemical variations would require unreasonably large ranges (i.e., 2-6 GPa) for a single eruption. These single-eruption variations also extend far across compositional cut-offs that have been proposed to represent a lithosphere to asthenosphere transition, indicating that similar variability is evident at much smaller time and length scales.

Mineralogy and geochemistry of Table Legs Butte and Quaking Aspen Butte, Eastern Snake River Plain (ESRP), Idaho

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Links between Geomorphology and Geochemistry

Tholeiitic basalt shields on the ESRP generally consist of pahoehoe flows with low-angle (1-2°) slopes. Based on topographic profiles, shields with significant relief on the ESRP have been grouped into three geomorphic categories: low-profile, dome-shaped, and shields with caps. Table Legs Butte (TLB) and Quaking Aspen Butte (QAB) are capped shields that exhibit gentle (4-6°) medial slopes and a sharp transition to steep (20°-30°) proximal slopes. Hypotheses that may explain this geomorphology relative to low-profile shields are: (1) a geochemically evolved, higher viscosity magma, (2) increase in crystal content/abundance from distal to summit regions, or (3) a different petrologic evolution compared to other tholeiitic shields on the ESRP. TLB and QAB were evaluated in detail by petrographic microscopy, INAA, ICP-AES, and EMPA and then compared to published literature on other ESRP basalts.

Results and Conclusions of study

Relative to low-profile shields, TLB displays high crystal abundance (~ 25% plagioclase), overall steeper shield profile, and a coarse (up to 1cm) diktytaxitic texture. QAB has low (~ 4%) crystal abundance, a less-pronounced summit cap, and poorly developed diktytaxitic texture. Neither shield displays changes in crystal content or abundance from proximal to distal regions. Bulk major- and trace-element chemistry depicts two distinct batches of magma that lie on a single fractionation trend, with TLB being more evolved than QAB. Trace elements vary widely in both shields, with TLB showing 2X to 3X enrichment in incompatiable elements and QAB showing no enrichment relative to other low-profile tholeiitic shields. No apparent connection can be made between different shield types and degree of geochemical evolution. Isotopic and EMPA work in progress will be applied to petrologic modeling techniques (MELTS and QUILF) for final results.

References

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