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The role of magma mixing, identification of mafic magma inputs, and structure of the underlying magmatic system at Mount St. Helens

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ABSTRACT

Mount St. Helens (MSH) volcano, in the southern Washington Cascades arc, has produced dominantly dacitic to andesitic magmatic products over the last 300 ka. Basaltic to basaltic andesitic magmas erupted only during the relatively brief (ca. 2100–1800 yr B.P.) Castle Creek period from vents separated by no more than a few kilometers. They provide a unique perspective on the evolution of this volcano. Despite close temporal and spatial proximity, these mafic magmas define two distinct compositional lineages: (1) low-K tholeiites (LKT) and (2) basalts of "oceanic island" or intraplate affinity (or IPB). Both lack typical arc geochemical signatures and appear to derive from distinct mantle sources, neither of which has been significantly modified by slab-derived fluid or melt components. No true calc-alkalic basalts have erupted from MSH despite its obvious arc setting. Each lineage includes derivative lavas that range from ~7 to 5 wt% MgO and ~49 to 55 wt% SiO_2, and both are slightly porphyritic with dominantly olivine and plagioclase, minor spinel, and trace clinopyroxene in some but not all samples. With respect to incompatible elements (e.g., K, La, Nb, Th, etc.), compositional trends for the two lineages are dramatically different and inconsistent with simple fractional crystallization processes. The data instead suggest that each lineage was produced dominantly by mixing between distinct parental LKT and IPB basaltic magmas and material of intermediate composition roughly similar to average MSH andesite. Mineralogical characteristics of macrocrysts in MSH basalts indicate that they do not represent equilibrium assemblages. Olivine compositions and textures in some samples implicate accumulation of crystals formed from multiple magmas, and evidence for magma mixing is reinforced by the rare presence of "blebs" of rhyolitic glass. These assemblages of crystals presumably are derived from different magmas and/or older MSH magmatic products (including crystal mush zones) within crustal conduit systems.

Extrapolation of compositional trends ("mixing arrays") to higher MgO content implicates the involvement of three types of parental magma: primitive LKT as well as distinct nepheline- and hypersthene-normative IPBs (or ne-IPB and hy-IPB), variants of which have erupted repeatedly from monogenetic vents in this sector of the Cascades. Such magmas are interpreted to form from distinct lherzolitic mantle sources (less fertile, with lower clinopyroxene content for LKT) at depths on the order of 80 (LKT) and 50–60 (IPBs) kilometers, under near-anhydrous conditions, in response to decompression rather than flux-melting.

We also report a set of self-consistent estimates of temperature, pressure, water content, magma density, and weight fraction of "andesitic" mixing component for samples of each lineage. These parameters are highly correlated and serve to constrain the structure of the magma feeder system beneath MSH. A dynamic continuum of melt compositions is likely present, controlled principally by temperature and density gradients within the system. We envisage that during Castle Creek time the most primitive basaltic magmas formed distinct reservoirs in the deep crust, with the ne-IPB variant near 28 km depth and the LKT variant near 23 km. More silicic members of these lineages appear to have evolved at depths between ~20–15 km. We suggest that reservoir depths were controlled mainly by magma density that, in turn, is largely determined by the degree of mixing with "andesitic" components at crustal depths. This configuration implies a vertical magmatic plexus with connections extending well into the upper mantle. The sharp chemical distinction between the LKT and IPB mixing arrays suggests that the respective feeder systems were isolated and rarely interacted despite their close proximity.

Finally, it appears that the presence of large, complex, and long-lived conduit systems beneath stratovolcanoes can act as "magma traps," within which deeper-seated (mantle) inputs are prone to modification by interaction with stored magmas and their differentiation products. In contrast, the occurrence of relatively primitive basalts from monogenetic vents distal from stratovolcanoes implies that diverse basaltic magmas ascend beneath virtually the entire arc segment and that the true complexity of this "mantle wind" is locally masked by modifications within the crust.

Keywords: Cascades arc, Mount St. Helens, basalts, magma mixing, magma plumbing

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