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Origin of temporal compositional trends in monogenetic vent eruptions: Insights from the crystal cargo in the Papoose Canyon sequence, Big Pine Volcanic Field, CA

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ABSTRACT

Many monogenetic vents display systematic temporal–compositional variations over the course of eruption. Previous studies have proposed that these trends may reflect variable degrees of crustal assimilation, or melting and mixing of heterogeneous mantle source(s). Discrimination between these two endmember hypotheses is critical for understanding the plumbing systems of monogenetic volcanoes, which pose a significant volcanic hazard in many areas. In this study, we examine the Papoose Canyon (PC) monogenetic vent in the Big Pine Volcanic Field (BPVF), which had been well characterized for temporal–compositional variations in erupted basalts. We present new major and trace element and Sr–Nd–Pb–O isotopic data from the PC "crystal cargo" (phenocrysts and xenoliths). Comparison of "crystal cargo" and host basalt provides new constraints on the history of magma storage, fractionation, and crustal contamination that are obscured in the bulk basalts due to pre- and syn-eruptive magma mixing processes.

The abundances of phenocrysts and ultramafic xenoliths in the PC sequence decrease up-section. Olivine and clinopyroxene phenocrysts span a wide range of Mg# (77–89). The majority of phenocrysts are more evolved than olivine or clinopyroxene in equilibrium with their host basalts (Mg# = 68–71, equilibrium Fo ≈ 85–89). In addition, the ultramafic xenoliths display cumulate textures. Olivine and clinopyroxene from ultramafic xenoliths have Mg# (73–87) similar to the phenocrysts, and lower than typical mantle peridotites. Sr–Nd–Pb isotope compositions of the xenoliths are similar to early PC basalts. Finally, many clinopyroxene phenocrysts and clinopyroxene in xenoliths have trace element abundances in equilibrium with melts that are more enriched than the erupted basalts. These features suggest that the phenocrysts and xenoliths derive from melt that is more fractionated and enriched than erupted PC basalts. Pressure constraints suggest phenocrysts and ultramafic xenoliths crystallized at ∼5–7 kbar, corresponding to mid-crust depths. Correlations between HFSE depletion and Sr–Nd–Pb isotopic compositions, high $\delta^{18}O$ values in olivines, and radiogenic Os isotopic compositions in whole rocks also suggest incorporation of a crustally contaminated component.

We propose that the phenocrysts and ultramafic xenoliths derive from melts that ponded and fractionated and assimilated continental crust, possibly in mid-crustal sills. These melts were drained and mixed with more primitive melts as the eruption began, and the temporal–compositional trends and decreasing crystal phase abundances reflect gradual deflation and exhaustion of these sills as the eruption progressed. The isotopic variations in the PC sequence span much of the compositional range observed in the BPVF. Evidence for variable crustal contamination of PC basalts suggests that much of the isotopic variation observed in the BPVF may also reflect crustal contamination rather than mantle source heterogeneity as previously proposed. In addition, evidence of pre-eruptive magma ponding and fractionation, if applicable to other monogenetic vents, may have significant implications for monitoring and hazard assessment of monogenetic volcano fields.

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1. Introduction

Monogenetic vents are small volcanoes that often occur in clusters and are active for a single eruption or short-lived eruptive cycle (months to decades). Monogenetic vent fields represent a significant volcanic hazard in many regions of the world (e.g., Auckland, Mexico City; Bebbington and Cronin, 2011; Siebe and Macías, 2006). An improved understanding of the mechanisms of melt generation and in particular melt storage within monogenetic vent fields will allow better assessment of volcanic hazards associated with monogenetic vents. If magmas erupted from particular vent fields are typically stored within crustal sills prior to eruption (e.g., Erlund et al., 2010), future eruptions may be preceded by sill emplacement or inflation, providing a possible early warning for impending eruption. However, if melts directly ascend from the mantle source to surface with little or no crustal storage prior to eruption (e.g., Blondes et al., 2008), prediction of such eruptions may be difficult.

Many monogenetic vents display significant chemical and isotopic variations during a single eruptive cycle, which can mimic compositional variations observed in entire volcanic fields or regions over longer timescales (e.g., Garcia et al., 2000; Blondes et al., 2008; Erlund et al., 2010). These geochemical variations may provide important constraints on the processes of melt generation and transport. In some cases these short-term variations are proposed to reflect melt generation and extraction from heterogeneous mantle sources, which would suggest rapid magma ascent from source to surface with limited shallow storage (e.g., Blondes et al., 2008; Rasoazanamparany et al., 2015). In other cases, these temporal variations appear related to temporally varying degrees of crustal contamination, more consistent with protracted pre-eruptive magma storage (e.g., McBirney et al., 1987; Erlund et al., 2010).

In addition, distinguishing between mantle and crustal signatures in continental basalts has been a long-standing and vexing problem. Geochemical variations in basalts from the Basin and Range are widely used to constrain the composition and evolution of their mantle sources (e.g., Beard and Glazner, 1995; Gazel et al., 2012). However, basalts represent only indirect probes of mantle composition. Processes such as melt generation, migration, and melt–crust interaction all can affect the compositions of erupted lavas. Distinguishing between mantle versus crustal signatures is particularly difficult in continental settings, because the signatures of crustal contamination may qualitatively resemble the chemical and isotopic signatures of melt generation from metasomatized continental lithospheric mantle (e.g., Hildreth et al., 1991; Glazner et al., 1991). Therefore, understanding the history of magma ponding and evolution of continental basalts may allow better assessment of potential crustal contamination and more accurate interpretation of mantle source evolution.

In this study, we examine the crystal cargo of the Papoose Canyon (PC) monogenetic vent sequence from the Big Pine Volcanic Field (BPVF), California, a well-documented monogenetic vent with clear temporal–compositional trends (Blondes et al., 2008). Major and trace element and isotope variations in olivine and clinopyroxene phenocrysts and ultramafic xenoliths provide new constraints on the pre-eruptive magma storage and mixing history at PC vent, and allow us to test crust versus mantle origins for the observed temporal–compositional trends.

2. Background

The BPVF is a monogenetic volcano field situated in Owens Valley, bounded to the east and west by the Inyo-White Mountains and the Sierra Nevada. With the exception of one silicic vent, lavas erupted at the BPVF are primarily mafic in composition, ranging from basanites to alkalic and sub-alkalic basalts (Bierman et al., 1991). Most vents erupted between 0.1 and 0.8 Ma, with the oldest documented eruption at ∼1.2 Ma (Gillespie et al., 1984; Bierman et al., 1991; Blondes et al., 2008). The origin of BPVF volcanism is commonly attributed to Basin-and-Range regional extension and associated lithosphere thinning and/or delamination (e.g., Beard and Glazner, 1995; Lee et al., 2001; Wang et al., 2002).

Basalts erupted at the BPVF span a range of major and trace element and isotope compositions. For example, whole rock SiO_2 abundances vary from 44.1 to 53.0 wt.%, olivine-fractionation-corrected Sr concentrations vary from ∼900 to 2300 ppm and $^{87}Sr/^{86}Sr$ ranges from 0.70534 to 0.70648. (Ormerod et al., 1988, 1991; Rogers et al., 1995; Beard and Glazner, 1995; Mordick and Glazner, 2006; Blondes et al., 2008). Ormerod et al. (1991) suggested that the variations in trace element abundances reflect different degrees of partial melting of a relatively homogeneous mantle source. However, this cannot account for observed isotopic variations. Beard and Glazner (1995) proposed that the observed compositional variations reflect melt generation from heterogeneous metasomatized continental lithospheric mantle. More recently, Gazel et al. (2012) suggested that melt generation depths of BPVF basalts have shifted from asthenospheric mantle to the lithosphere–asthenosphere boundary over time, resulting in increased incorporation of lithospheric mantle components in younger BPVF basalts.

Several individual eruption sequences in the BPVF display compositional variations (Blondes et al., 2008). This study focuses on the PC sequence (760.8 ± 22.8 ka) because this sequence is well exposed and displays significant temporal–compositional variations, and previous geochemical characterization of PC whole rocks provides important context for the new crystal cargo data presented here (Blondes et al., 2008). The PC sequence is cut and exposed by the Papoose Canyon valley, which allows stratigraphically-controlled sampling of the entire sequence. Over the course of the PC eruption, the concentrations of highly incompatible trace elements decreased by up to a factor of ∼2 (e.g., La concentrations decreased from 66 to 33 ppm). This decrease in trace element concentrations was accompanied by decreasing $^{87}Sr/^{86}Sr$ (0.7063–0.7055) and increasing ε_{Nd} (−3.5–−1.1) (Blondes et al., 2008). The PC sequence is overlain by two younger vents (Quarry and Jalopy) at the western end of the valley. Basalts from the younger vents are chemically distinct from the older PC basalts (e.g., PC basalts have systematically higher Nb concentrations; Blondes et al., 2008; Gazel et al., 2012).

3. Samples and methods

3.1. Field observations and samples

The PC vent is located at the easternmost part of the BPVF (Blondes et al., 2008). The vent sits on top of dolomitic country rock. The PC sequence contains both massive units and loose scoria. The massive units have sparsely vesicular interiors and more vesicular margins. The interiors of these units appear mostly fresh, with scattered secondary zeolite/calcite minerals filling vesicles. The scoria and massive unit margins are generally more altered and oxidized. No soil horizons are observed between layers within the sequence, consistent with a monogenetic origin for the sequence. Overall, PC basalts have low phenocryst abundances, with phenocryst mineralogy dominated by olivine and clinopyroxene (cpx). Abundant pyroxene-rich ultramafic xenoliths (70–90% modal cpx and 10–30% modal olivine) and some carbonate crustal xenoliths are present in the early eruption sequence. Both ultramafic and carbonate xenoliths are sub-rounded to rounded.

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