Earth and Planetary Science Letters 459 (2017) 252–263

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Formation of obsidian pyroclasts by sintering of ash particles in the volcanic conduit

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ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 18 November 2016
Accepted 20 November 2016
Available online 6 December 2016
Editor: T.A. Mather

Keywords:
obsidian
explosive eruption
volatiles
Mono Craters
degassing
vesicle

ABSTRACT

The ranges in intensity and style of volcanic eruptions, from highly explosive Plinian eruptions to quiescent lava extrusions, depend on the style and efficiency of gas loss from ascending magma. Obsidian pyroclasts – small, glassy pieces of quenched magma found in some volcanic tephra beds – may preserve valuable information about magma degassing in their vesicle textures and volatile contents. Accurate interpretation of their textures and volatiles, however, requires understanding the mechanism of formation of the pyroclasts. Obsidian pyroclasts from the ca. 1325–1350 C.E. North Mono eruption of Mono Craters (CA, USA) were analyzed and found to have H_2O and CO_2 contents indicating that they were formed at pressures in the approximate range of 3–40 MPa. Many also contain domains with differing vesicle textures, separated by boundaries containing xenocrystic material, indicating that they are composed of smaller fragments that have sutured together. More than half of the pyroclasts analyzed contained small (~10 μm), highly distorted vesicles, with multi-cuspate morphology, interpreted as the remnants of interstitial gas trapped amongst sintered fragments of melt/glass. Rounded vesicles are also common and are interpreted to result from surface tension-driven relaxation of the distorted vesicles. Calculated timescales of sintering and relaxation are consistent with timescales for pyroclast formation indicated by H_2O re-equilibration within the heterogeneous pyroclasts. This sintering model for the origin of obsidian pyroclasts is further supported by the observation that spherical vesicles are found mainly in H_2O-rich pyroclasts, and distorted vesicles mainly in H_2O-poor pyroclasts. We conclude that obsidian pyroclasts generated during the North Mono eruption were formed by cycles of fragmentation, sintering/suturing, and relaxation, over a very wide range of depths within the conduit; we find no evidence to support pumice (foam) collapse as the formation mechanism. Similar textures, and the occurrence of xenolithic material, in obsidian pyroclasts in other eruptions suggest that sintering may be generally responsible for the origin of obsidian pyroclasts. Our conceptual model indicates that volatile contents in obsidian pyroclasts reflect both degassing of bubbly magma and the composition of gas trapped between sintering particles.

1. Introduction

The style of silicic volcanic eruptions depends on the behavior of gas that exsolves from magma during ascent (Eichelberger et al., 1986; Jaupart and Allegre, 1991; Gonnermann and Manga, 2003). In the current paradigm, if the gas remains trapped in the bubbly magma (closed-system degassing), then the magma will eventually fragment, driving explosive activity. If, instead, the magma becomes permeable, allowing the gas to escape (open-system degassing), then the magma does not fragment, but collapses to a bubble-poor liquid and effuses as lava (Eichelberger et al., 1986).

Evidence for magma degassing (exsolution of magmatic volatiles from the melt) and outgassing (loss of exsolved gas from the magma) is preserved in obsidian pyroclasts – glassy pieces of quenched magma found in some volcanic tephras (e.g., Eichelberger and Westrich, 1981; Taylor et al., 1983; Newman et al., 1988; Rust et al., 2004; Barnes et al., 2014). Variations in concentrations and isotopic compositions of volatiles among obsidian pyroclasts often appear to follow trends expected from closed-system degassing (Taylor et al., 1983; Newman et al., 1988; Barnes et al., 2014). This presents a problem because obsidian py-

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http://dx.doi.org/10.1016/j.epsl.2016.11.037
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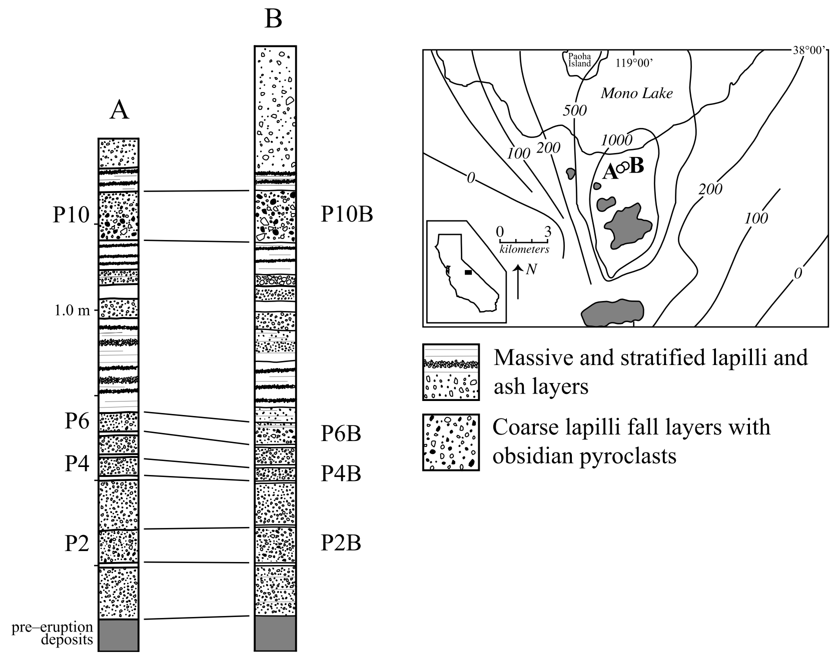

Fig. 1. Schematic stratigraphic sections for pits A and B, both of which were ∼1.5–1.75 m in thickness. Pumice fragments and obsidian pyroclasts were collected from layers labeled "P" in the two pits. Pit A is the same as that in Barnes et al. (2014). Inset map shows the location of the two pits, relative to the positions of the obsidian domes and the cumulative tephra isopachs (in mm) for the ca. 1325–1350 C.E. Mono Craters eruption (modified from Newman et al., 1988).

roclasts are vesicle-poor, yet closed-system degassing implies that gas bubbles remain within the packet of magma in which they form. Various models have been proposed to explain this apparent conundrum, hypothesizing that the closed-system-like volatile signatures arise from disequilibrium bubble growth (Gonnermann and Manga, 2005) or from buffering the magma by CO_2-rich gas that streams through brecciated magma (Rust et al., 2004). Rust et al. (2004) also propose that some obsidian pyroclasts form by 'annealing' of glass/melt fragments at the conduit margin, challenging the foam-collapse model for their origin (Eichelberger et al., 1986).

In this study, we investigate the origin and evolution of vesicles in obsidian pyroclasts from the most recent eruption of Mono Craters (Sieh and Bursik, 1986) by comparing vesicle textures to the preserved volatile contents. Based on our observations we go further than Rust et al. (2004) and argue that most, if not all, of the obsidian pyroclasts originate from sintering of small glass/melt fragments in the conduit (sintering is used in preference to annealing, following Wadsworth et al., 2014, 2016). Volatile contents in obsidian pyroclasts thus reflect the composition of gas trapped between sintered ash fragments, rather than preserve degassing trends.

2. Methods

Obsidian pyroclasts were collected from the North Mono tephra bed, dated to the interval 1325–1350 C.E. (Sieh and Bursik, 1986; Bursik, 1993). The eruption began with a series of sub-plinian explosions that spread a thick blanket of tephra to the north and east of Mono Craters (Fig. 1). The eruption shifted to producing pyroclastic surges and flows, and ended by extruding at least five lava domes and flows (coulees) (Sieh and Bursik, 1986). As many as 10 vents were active, and their alignment, plus the extrusion of separate lavas, suggest that the eruption was fed from one or more dikes (Sieh and Bursik, 1986).

Samples were collected from two pits dug into the North Mono tephra (Fig. 1). The stratigraphy is the same between pits, and can be matched with that described in Sieh and Bursik (1986); our layers P2, P4, and P6 match their Beds 2, 4, and 6. The relatively

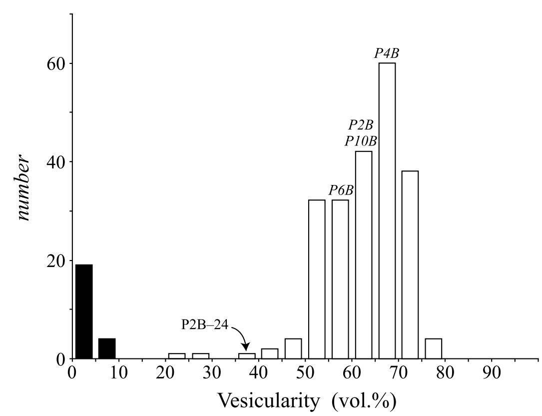

Fig. 2. Vesicularity distributions of pumice lapilli (open bars) and obsidian pyroclasts (solid bars). Tephra layer names mark the median pumice vesicularities. Although only 23 obsidian pyroclasts were measured, these are representative of the range of textures seen. P2B-24 is the one pumice lapilli that consists of smaller vesicular fragments sutured together with crystal-rich ash (see Fig. 3f).

lithic- and obsidian-rich nature of P10 suggests it is Bed 7, but it could also be a coarse layer in their Gray Glassy Beds. Bursik (1993) found that Beds 1–6 have ∼60–90% pumice and ∼1–20% obsidian pyroclasts, with different types of lithics making up the difference. Their Bed 7 contains ∼40% obsidian pyroclasts and subordinate amounts of pumice and lithics. Although we did not sieve our tephra layers, those proportions are consistent with our observations.

A total of 81 obsidian pyroclasts collected from four tephra layers were analyzed in this study (Fig. 1). All methods are discussed in the Supplemental text; results are presented in Supplemental Tables A.1 to A.7. Vesicle textures were analyzed in 80 of the obsidian pyroclasts. Volatile contents of 54 were measured in this study; volatile contents of the other 27 were reported in Barnes et al. (2014). Together, the measured volatile contents span the entire range of values reported by Newman et al. (1988) and Rust et al. (2004). Vesicularities of 221 pumice and 23 obsidian pyroclasts were also measured.