Journal of Volcanology and Geothermal Research 192 (2010) 69–84

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Linking experimental and natural vesicle textures in Vesuvius 79AD white pumice

Thomas Shea [a,*], Lucia Gurioli [b,c,d], Jessica F. Larsen [e], Bruce F. Houghton [a], Julia E. Hammer [a], Katharine V. Cashman [f]

[a] Department of Geology and Geophysics, SOEST, University of Hawaii, 96822, Honolulu, HI, United States
[b] Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, BP 10448, F-63000 Clermont-Ferrand, France
[c] CNRS, UMR 6524, LMV, F-63038 Clermont-Ferrand, France
[d] IRD, R 163, LMV, F-63038 Clermont-Ferrand, France
[e] Geophysical Institute, University of Alaska Fairbanks, 99775, Fairbanks, AK, United States
[f] Department of Geological Sciences, University of Oregon, 97403, Eugene, OR, United States

ARTICLE INFO

Article history:
Received 16 July 2009
Accepted 16 February 2010
Available online 3 March 2010

Keywords:
vesicles
phonolite
Vesuvius
textural characterization
decompression experiments
size distribution
magma ascent rate

ABSTRACT

Vesicle populations in volcanic pumice provide a partial record of shallow magma ascent and degassing. Here we compare pumice textures from the well-characterized 79AD Vesuvius eruption to those generated during isothermal decompression experiments. Three series of experiments were conducted using starting material from the first two phases of the eruption (eruptive units EU1 and EU2). Samples were decompressed from 100 or 150 MPa to final pressures of 10–25 MPa using conditions appropriate for simulating eruption conditions ($T = 850$ °C, $dP/dT = 0.25$ MPa/s). The experiments differed not only in starting material but also in temperature at which samples were annealed prior to decompression, which determined the initial number of crystals present in the melt. Results show that experiments approach the vesicle number densities and sizes of pumice samples, but show narrower size distributions. The wider size range of pumice samples suggests continuous, rather than instantaneous nucleation, which may reflect non-linear rates of decompression. All experiments exhibited equilibrium degassing, a process that was probably aided by heterogeneous bubble nucleation on oxide microlites. We conclude that delayed bubble nucleation cannot explain the explosivity of the Vesuvius eruption, which instead appears to require high rates of magma decompression.

1. Introduction

Vesicles in volcanic rocks provide valuable information on the processes occurring in magma conduits and storage systems (e.g. Cashman and Mangan, 1994). Three complementary approaches provide constraints on vesiculation in magmas: textural measurements, laboratory experiments, and physical/numerical models. Textural measurements of vesicle size, number and spatial distribution in natural samples are used to infer the processes responsible for their formation (e.g., Klug and Cashman, 1994; Klug et al., 2002; Polacci et al., 2003; Gurioli et al., 2005; Sable et al., 2006; Adams et al., 2006, Lautze and Houghton, 2007; Polacci et al., 2007). Although natural tephra samples are the best available "tracers" of vesiculation in any eruption, they represent a frozen textural state, which might have been acquired prior to, during, and after magmatic fragmentation. Decompression experiments document processes of bubble nucleation, growth, coalescence, and collapse that may occur during magma ascent, although the small volumes of material used often prevent scaling of vesicle size, number and porosity to natural systems. Models of bubble nucleation and growth link experiments to conduit processes, and ultimately, shed light on conditions required to produce violent explosive eruptions (Toramaru, 1989; Toramaru, 1995; Lyakhovsky et al., 1996; Jaupart, 1996; Vergniolle, 1996; Lovejoy et al., 2004; Mangan et al., 2004; Massol and Koyaguchi, 2005; Yamada et al., 2005; Toramaru, 2006; Gonnermann and Manga, 2007).

Of the three approaches described above, laboratory experiments provide a critical link between field observations and modeling through quantification of kinetic parameters such as bubble nucleation and growth rates, volatile solubility, diffusivity, and surface tension. Most experimental vesiculation studies have examined rhyolitic magmas (Hurwitz and Navon, 1994; Lyakhovsky et al., 1996; Gardner et al., 1999; Mourtada-Bonnefoi and Laporte, 1999; Mangan and Sisson, 2000; Gardner et al., 2000; Larsen and Gardner, 2000; Mourtada-Bonnefoi and Laporte, 2002; Martel and Schmidt, 2003; Mourtada-Bonnefoi and Laporte, 2004; Larsen et al., 2004; Lensky et al., 2004; Burgisser and Gardner, 2005; Gardner, 2007; Cluzel et al., 2008) because they produce the most violent eruptions, and their high viscosity precludes problems associated with rapid microlite crystallization and bubble-melt decoupling in laboratory capsules. Sparser experimental data exist on lower viscosity melts such as basalts (Bai et al., 2008), dacites (Mangan et al., 2004; Suzuki et al., 2007) and phonolites (Larsen and Gardner, 2004;

* Corresponding author. Tel.: +1 808 956 8558.
E-mail address: tshea@hawaii.edu (T. Shea).

0377-0273/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2010.02.013

Larsen et al., 2004; Iacono Marziano et al., 2007; Larsen, 2008; Mongrain et al., 2008).

Here, we examine the decompression and vesiculation of phonolites at conditions relevant to the 79AD eruption of Vesuvius, and compare experimental textures to those of pumice deposited during the opening and first Plinian phases of the eruption. Both natural and experimental data are then compared to models of bubble formation to determine (1) limiting conditions of equilibrium H_2O exsolution, (2) the correspondence between number densities, modal vesicle size, and size distribution of pumice and experimental samples, and (3) the influence of microlites on nucleation. We find that 79AD K-phonolites nucleate heterogeneously on microlites, exsolve efficiently even at low temperatures, and produce number densities close to those measured in natural samples. On the other hand, bubble size distribution comparisons between experimental and natural samples suggest that natural ascent processes are probably more complex than what has been tested to date in the laboratory environment. We suggest that the most viable way to mimic natural bubble size populations through experiments is to apply non-linear decompression pathways, possibly resulting in multiple nucleation and growth pulses.

2. The 79AD eruption of Vesuvius

Nearly 2000 years ago, Vesuvius volcano produced one of the largest and deadliest historical eruptions, burying the Roman towns of Herculaneum, Pompeii, Oplontis and Stabiae under meters of both fallout tephra and pyroclastic density current (PDC) deposits (e.g. Lirer et al., 1973; Sigurdsson et al., 1982, 1985; Cioni et al., 1992). The eruption (volcanic explosivity index VEI = 6, Cioni et al., 2008) lasted over 20 h and produced a total of 2–3 km^3 of deposits, calculated as dense rock equivalent (DRE). Pumice composition and color varied from a white phonolitic to a gray tephri-phonolitic composition during the course of the eruption, which is thought to reflect pre-eruptive zoning of the magma reservoir (Sigurdsson et al., 1990; Cioni et al., 1995). According to this model, the magma that produced white pumice (hereafter referred to as “white” magma) was an un-erupted remnant from the ~3900 BP eruption of Avellino, which had differentiated and cooled to ~850 °C (Cioni, 2000) over about 2000 years (Lirer et al., 1973, Cioni et al., 1995). During the 79AD eruption, batches of hotter tephritic magma intruded the storage region, heated the lower portion of the white magma to ≤925 °C (Shea et al., 2009) and mixed with white magma to produce the tephri-phonolite, which produced the later gray pumice deposits.

Herein, we focus on the white magma and, more specifically, on the opening sub-Plinian (EU1) and Plinian (EU2) stages. Our objective is to characterize vesiculation processes from the onset to the sustained plinian phase of the eruption. The opening phase (EU1) formed a ~15 km-high buoyant column that was advected eastward by lower tropospheric winds (Sigurdsson et al., 1985) and deposited fine-grained pumice tens of kilometers from the vent (Fig. 1a and b). The unit varies from 0 to 15 cm in thickness (Fig. 1c) and blankets the flanks of the volcano. After a small column collapse event generated a poorly dispersed PDC (EU1pf, Cioni et al., 2000), the sustained activity increased in intensity and a much higher ~25–30 km plume formed (Fig. 1b), was carried south-east by stratospheric winds (Rolandi et al., 2008), and deposited EU2 pumice hundreds of kilometers from the eruptive center (Sigurdsson et al., 1985). EU2 is ≤140 cm thick at the base of Vesuvius (Cioni et al., 1992), thins outward and then thickens again (>100 cm) towards the Sorrento peninsula (Sigurdsson et al., 1985; Fig. 1a, c).

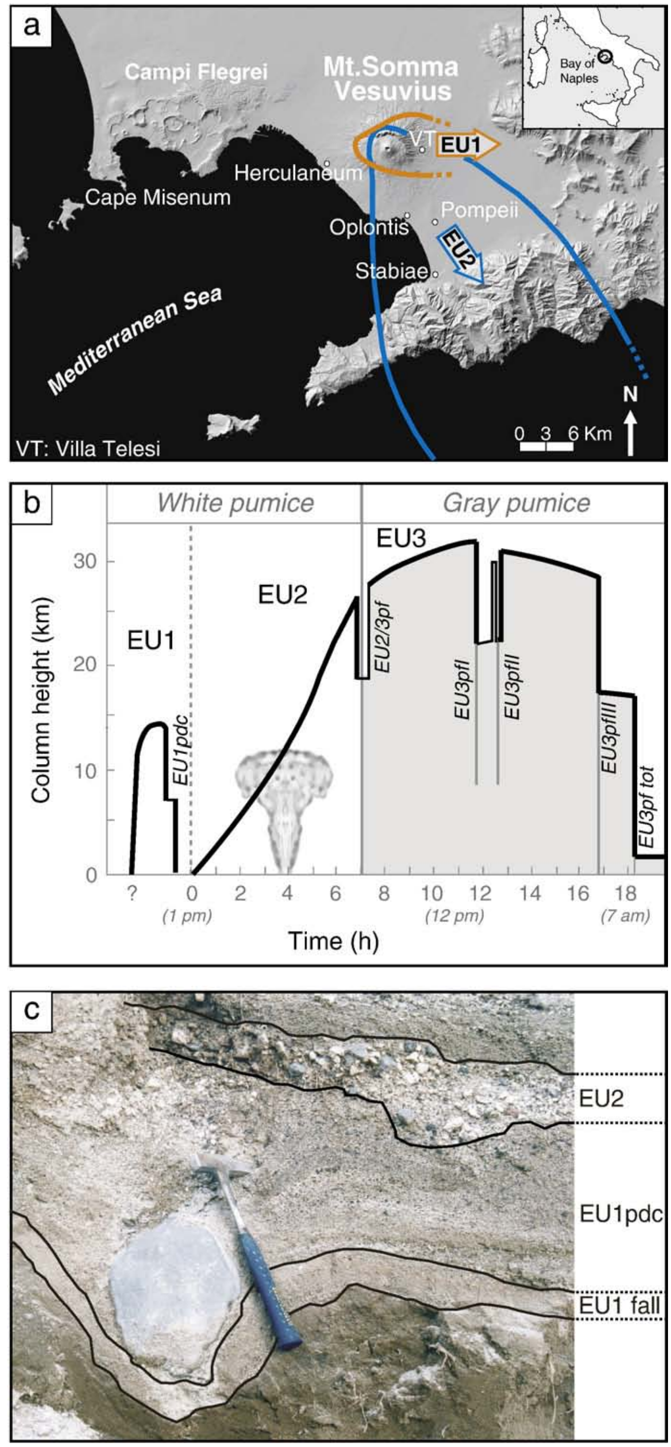

Fig. 1. (a) DEM of the Bay of Naples and the region surrounding Mt. Vesuvius in Italy, overlain by 10 cm-isopachs of fallout deposits ejected during both the opening (EU1) and early Plinian (EU2) phases of the 79AD eruption. Note how the dispersion is much more reduced for EU1. Pumice samples from EU1 and EU2 used in this study were collected at Villa Telesi and Pompeii, respectively. (b) Interpretative plot of eruptive column height in function of time through the eruption, along with the approximate timing of various fallout and pyroclastic density current events (modified from Carey and Sigurdsson, 1987). (c) Outcrop showing EU1 and EU2 separated by a pyroclastic density current deposit (EU1pdc). Hammer for scale.

3. Background: textural investigation of products from the 79AD eruption and vesiculation experiments in phonolites

The products of the 79AD eruption of Vesuvius have been characterized by Gurioli et al. (2005), who examined textural evidence for the origin of changes in eruptive behavior during two important transitions (i.e. white to gray pumice EU2–EU3 and sustained plinian activity to caldera collapse EU3–EU4) using vesicle and crystal textures. We focus on conditions related to the onset of eruptive activity (EU1) and subsequent transition to the first Plinian phase (EU2). In particular, we used decompression experiments to explore the effects of varying starting conditions (composition and microlite content) on conditions of vesicuation and, by