Journal of Volcanology and Geothermal Research 195 (2010) 31–47

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Diverse patterns of ascent, degassing, and eruption of rhyolite magma during the 1.8 ka Taupo eruption, New Zealand: Evidence from clast vesicularity

Bruce F. Houghton [a,*], Rebecca J. Carey [a], Katharine V. Cashman [b], Colin J.N. Wilson [c], Barbara J. Hobden [d], Julia E. Hammer [a]

[a] Department of Geology and Geophysics, University of Hawai'i, 1680 East-West Road, Honolulu, HI 96822, USA
[b] Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403, USA
[c] School of Geography, Environment and Earth Sciences, Victoria University, Wellington 6140, New Zealand
[d] Department of Earth Sciences, University of Waikato, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 12 February 2010
Accepted 9 June 2010
Available online 21 June 2010

Keywords:
explosive volcanism
vesiculation
conduit process
Plinian
Taupo eruption

ABSTRACT

The 22 km^3 (DRE) 1.8 ka Taupo eruption ejected chemically uniform rhyolite in a wide range of eruptive styles and intensities. The 7 eruptive units include the 'type examples' of phreatoplinian (units 3 and 4) and ultraplinian fall (unit 5) deposits, and low-aspect-ratio ignimbrite (unit 6). Contrasts in bulk vesicularity, vesicle (and microlite) number densities and the size distributions of bubbles (and crystals) in the Taupo ejecta can be linked to the influence of shallow conduit processes on volatile exsolution and gas escape, before and during eruption, rather than changes in pre-eruptive chemistry. Existing work has modeled the individual phases of this complex eruption but not fully explained the abrupt shifts in style/intensity that occur between phases. We link these rapid transitions to changes in vent position, which permitted contrasts in storage, conduit geometry, and magma ascent history.

Samples in the study show that coalescence of bubbles was a late-stage process in the pre-fragmentation degassing of even the most rapidly ascending magma, but, in most cases, nucleation of new bubbles continued until close to fragmentation. In the two phases of the Taupo eruption linked to dome or cyptodome formation, we can also recognize an influence of onset of permeability, partial outgassing, limited syn-eruptive crystallization, and bubble collapse. Post-fragmentation expansion or contraction of vesicles was only marked in some pumices within the deposits of the two heat-retentive yet nonwelded pyroclastic density currents (units 5B and 6).

We can recognize three different types of history of ascent, bubble nucleation, and degassing for the Taupo eruption. Units 1, 2 3, 5, and 6 involved magma that ascended rapidly under the southern and central portions of the vent system and underwent late-stage closed system, coupled vesiculation without syn-eruptive crystallisation of microlites. The limited contrasts in textures amongst these units reflect only slightly different ascent histories, including slower rise permitting extended bubble coalescence (unit 1), rapid, accelerating ascent (units 2, 3 and 5), and exceptionally rapid decompression and ascent at the time of highest mass discharge rates (unit 6).

In contrast to all these units, the unit 4 magma also rose rapidly initially but then underwent some degree of limited and shallow storage, permitting variable degrees of prolonged bubble maturation (growth and coalescence), development of permeability and outgassing, under the northern portion of the 10-km-long vent system, probably beginning at the time of eruption of units 1–3 from the southern portion of the fissure. Finally, the magma which formed the late-stage dome (unit 7), remained deeper in the plumbing system for an extended time permitting limited growth of microphenocrysts, (perhaps in response to partial depressurisation occurring during the earlier phases of the eruption), before ascending and continuing to outgas in equilibrium fashion.

1. Introduction

1.1. Explosive eruption mechanisms and controls

The mechanisms and dynamics of large explosive eruptions represent formidable challenges to understanding whether for past eruptions, ongoing activity, or for future eruptive events. Such eruptions

* Corresponding author. Tel.: +1 808 9562561; fax: +1 808 9565512.
E-mail address: bhought@soest.hawaii.edu (B.F. Houghton).

0377-0273/$ – see front matter
doi:10.1016/j.jvolgeores.2010.06.002

may be highly destructive, often showing complex and seemingly random behavior in parameters such as eruptive intensity, which may vary by over 7 orders of magnitude (Table 1). Stable buoyant (Plinian) plumes may give way gradually or abruptly to dome growth, or paroxysmal pyroclastic density currents, or phreatomagmatic explosions, or an abrupt cessation of activity. Volcanologists are as yet unable to explain many aspects of this divergence in style and intensity, or, more importantly, to predict the behaviour of future large eruptions.

Reducing the human cost of volcanic crises requires better knowledge of what factors control the style and intensity of large explosive eruptions. The scale of all explosive eruptions of a size capable of being represented in the geological record inhibit close direct observations, and much of our understanding of such events derives from studies of the resulting pyroclastic products, coupled with geophysical data in active eruptions, and analogue and numerical modeling. From these data and models, there is now widespread acceptance of a number of basic controls on explosive eruption behavior.

In general, eruption intensity, duration and style are considered to be determined within either the region of magma storage, which provides the overpressure driving an eruption, or the volcanic conduit, where magma decompresses, loses volatiles, and sometimes partially crystallizes (Wilson et al., 1980; Jaupart and Tait, 1990; Jaupart and Allegre, 1991, Woods and Koyaguchi, 1994; Jaupart, 1996; Bower and Woods, 1998; Massol and Jaupart, 1999; Huppert, 2000; Papale, 2001; Gonnermann and Manga, 2007; Scandone et al., 2007). Even for the simplest of cases, with a magma with uniform chemical composition and initial volatile content, complex changes in eruptive style or intensity may be driven by:

(a) changing flow behaviour in the conduit (e.g., Kaminski and Jaupart, 1997; Papale et al., 1998; Denlinger and Hoblitt, 1999) as magma rheology alters in response to the changes in the concentrations of dissolved volatiles, bubbles and crystals (e.g., Hess and Dingwell, 1996; Manga et al., 1998; Papale et al., 1998; Llewellin and Manga, 2005; Massol and Koyaguchi, 2005; Gonnermann and Manga, 2007), or
(b) external environmental factors, such as widening of the conduit or the influx of external water (e.g., Barberi et al., 1989; Koyaguchi and Woods, 1996; Carey et al., 2009).

One key insight into conduit processes is the imprint that they leave on the microtextures of the eruption products (Cashman, 1992; Cashman and Mangan, 1994; Klug and Cashman, 1994; Gardner et al., 1996; Hammer et al., 1998, 1999; Mourtada-Bonnefoi and Mader, 2004; Carey et al., 2009). In many cases complexities in the characteristics of single pyroclasts or deposits can be shown to have arisen because of four additional factors:

(i) The presence of some form of compositional zonation in the magma chamber, which leads to systematic variations in the magma properties (e.g., viscosity and initial volatile content). These changing properties may act in addition to the physical controls listed above in controlling the style of eruptions. Notable examples of such compositional variations are the AD 79 eruption of Vesuvius (e.g., Cioni, 2000; Gurioli et al., 2005; Shea et al., 2009), and the 1912 eruption of Novarupta (Fierstein and Hildreth, 1992; Hildreth and Fierstein, 2000; Houghton et al., 2003; Adams et al., 2006a).
(ii) The presence of single versus multiple vents. If the magma is emplaced as a dike in the upper crust, multiple vents may erupt simultaneously or sequentially along the dike, with each vent (in principle) having the opportunity to show different behavior controlled by local parameters such as those listed in (a) and (b), above. Notable examples of this have occurred in basaltic fissure eruptions, such as Laki 1783 (Thordarson and Self, 1993) and Tarawera, 1886 (e.g., Sable et al., 2006, 2009; Carey et al., 2007) and are also known from rhyolite eruptions like Kaharoa 1314 (e.g., Nairn et al., 2001).
(iii) The possibility of eruptive breaks, which may occur in single- or multiple-vent eruptions (e.g., Nairn et al., 2001; Adams et al., 2006a) and are a challenge to quantify in any prehistoric eruption. Estimating the duration of such breaks is, however, important in disentangling the effects on magma properties of processes like gas loss and microlite growth, and deciphering whether these might have occurred prior to a continuous, uninterrupted eruption (e.g., in a shallow intrusion) or during time breaks in an episodic eruption. In addition, the recognition of eruptions starting and stopping may give valuable insights into the controls and feedback loops involved in magma chamber behaviour and how and when conduits are open or closed.
(iv) The presence of complex relationships between buoyant and non-buoyant plumes, the latter leading to the generation of pyroclastic density currents (PDCs). This contrast may be expressed as a one-way change from fall to pdc, or oscillatory behavior between the two regimes, or may reflect simultaneous contrasts in behavior of a single eruption plume. The buoyant/non-buoyant transition may be coincident with (i) that influences or merely accompanies the changing eruption style (e.g., Fierstein and Hildreth, 1992; Houghton et al., 2004; Gurioli et al., 2005).

To illustrate the ways in which these complexities may be disentangled through a combination of field-based and clast-specific observations, we address conduit and vent processes in the 1.8 ka eruption of Taupo volcano, New Zealand (Walker, 1980, 1981a,b; Walker and Wilson, 1985; Wilson, 1985; Smith and Houghton, 1995). This complex eruption of c. 35 km^3 magma demonstrates three of the four complexities outlined above, having evidence for multiple vents,

Table 1
Characteristics of the Taupo eruption, in comparison with documented 20th century silicic eruptions.

Eruption	Max inferred plume (km)	Vol DRE (km^3)	SiO_2 mtx glass (wt.%)	Phenocrysts (wt.%)	Range of mass discharge rate (kg s^{-1})		
					min		max
181 AD Taupo[1]	55	35	74	2–3.5	10^3	–	10^{10}
1991 Pinatubo[2]	40	4–5	68–77	15–47	10^3	–	10^9
1912 Novarupta[3]	26	13	73–78	2–50	10^3	–	10^8
1875 Askja[4]	28	0.3	69–73	<1	10^6	–	10^8
1980–6 St Helens[4]	25	1	68–80	30	10^3	–	10^7
1995 — Soufriere Hills[6]	15	.08	76–79	45–55	10^2	–	10^6
1991–5 Unzen[7]	<14	0.2	74–79	23–28	10^2	–	10^4

References: 1: Sutton et al. (1995, 2000), Wilson and Walker (1985), Wilson (1993); 2: Koyaguchi and Woods (1996); 3: Fierstein and Hildreth (1992), Hammer et al. (1999), Houghton et al. (2004); 4: Sparks (1978), Carey et al. (2009); 5: Blundy and Cashman (2001, 2005); 6: Melnik and Sparks (1999, 2002); 7:Nakada et al. (1999), Nakada and Motumura (1999).