Journal of Volcanology and Geothermal Research 175 (2008) 110–119

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Experimental volcanology on eruptive products of Unzen volcano

Bettina Scheu [a,b,*], Ulrich Kueppers [c,b], Sebastian Mueller [d,b], Oliver Spieler [b], Donald B. Dingwell [b]

[a] *Earthquake Research Institute, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, 113-0023 Tokyo, Japan*
[b] *Department of Earth and Environmental Sciences, University of Munich, Theresienstr. 41/III, 80333 Munich, Germany*
[c] *Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, 9501 - 801 Ponta Delgada, Açores, Portugal*
[d] *Department of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Bristol BS81RJ, UK*

ARTICLE INFO

Article history:
Accepted 24 March 2008
Available online 12 April 2008

Keywords:
Unzen
volcanology
fragmentation behavior
block-and-ash flow
porosity
permeability
elastic wave velocities
fracture toughness

ABSTRACT

Protracted dome-building eruptions may be profitably investigated using laboratory-based experiments. Density distribution studies on the pyroclastic flow deposits of Unzen 1990–1995 allow us to apply the results of experimental investigations on Unzen samples to the interpretation of the last eruption of Unzen. Here, primary laboratory experiments have focused on several aspects of the degassing (permeability) and the fragmentation behavior (threshold, speed, and efficiency). Those investigations have been flanked by analyses of flexural strength, fracture toughness, and seismic velocities, to provide new insights into eruption related processes. Here we present a review of these results and their application to the eruption dynamics of Unzen Volcano. We propose that efforts be made to incorporate routinely such comprehensive experimental analyses into the response to emerging volcanic crises in future.

1. Introduction

The investigation of physical processes leading to volcanic eruptions is becoming increasingly systematic, quantitative, and rigorous. This is substantially driven by the rising importance of hazard assessment and risk management, which requires reliable and quantitative assessments of volcanic processes in order to substantiate decisions during volcanic crises. Today such assessments rely on careful field investigations of the volcanic history, multiparameter monitoring of volcanic unrest, and simulation of eruptive scenarios. All of those approaches rely on an adequate mechanistic understanding of the processes of magmatic ascent and eruption, as well as the source mechanisms of monitoring signals. The inference of eruptive processes from the direct observation of explosive volcanic phenomena cannot rely solely on field data, as most eruption processes taking place in the conduit or the volcanic edifice are sufficiently remote from the observer that unambiguous answers are lacking. This situation has been enriched in the past decade significantly by the addition of experimental techniques to volcanology (Mader et al., 2004). Laboratory experiments lend valuable constraints to the interpretation of monitoring data, the simulation of eruptive events, and the interpretation of physical volcanology in the field. Here we propose that experimental volcanology can play an important role in crisis management for protracted dome-building eruptions. Using the example of Unzen 1990–1995, one of the best monitored and investigated eruptions worldwide (Fig. 1; (Nakada et al., 1999a) and articles therein), we illustrate how experimental volcanology is likely to accompany the next volcanic crisis. A brief overview of the investigated magma properties and the various used experimental techniques is provided by Table 1.

2. Eruption history of Unzen Volcano

Unzen Volcano started its activity about 500 ka ago in a tectonically extensional regime, the Unzen Graben. The eruption products are andesitic to dacitic in composition and consist mainly of thick lava flows, domes, and their collapse deposits (Hoshizumi et al., 1999; Nakada and Motomura, 1999).

The last eruption took place from 1990 to 1995 and ended a period of 198 years of quiescence. It was preceded by a period of approximately five years of elevated seismic activity (Umakoshi et al., 2001). The eruption started on 17 November 1990 with small phreatic eruptions, followed by phreatomagmatic explosions in February 1991. First lava extrusion occurred on 20 May 1991 and continued until February 1995. The eruption produced a complex dome at variable effusion rates, accompanied by frequent pyroclastic flows and some minor explosive events. High effusion rates resulted in exogenous dome growth, low effusion rates in endogenous growth.

* Corresponding author. Department of Earth and Environmental Sciences, University of Munich, Theresienstr. 41/III, 80333 Munich, Germany. Tel.: +49 89 2180 4259; fax: +49 89 21804176.
E-mail address: b.scheu@lmu.de (B. Scheu).

0377-0273/$ – see front matter
doi:10.1016/j.jvolgeores.2008.03.023

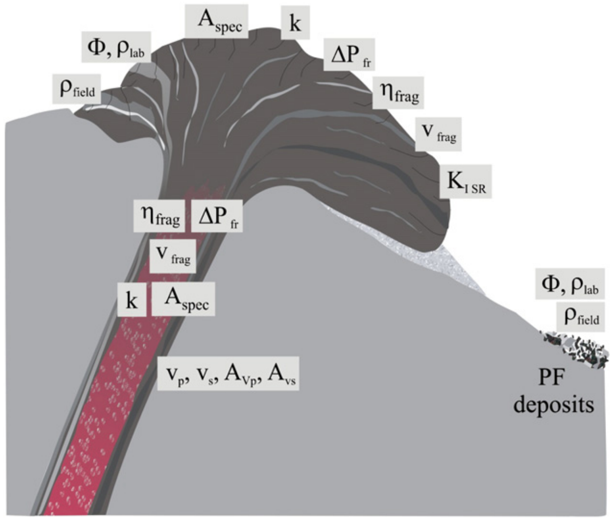

Fig. 1. Sketch of the Unzen Dome. All parameters investigated in this study are indicated at their relevant positions of the volcanic system. The symbols are as follows: ρ_{lab} (lab determined density), ρ_{field} (field determined density), Φ (porosity), ΔP_{fr} (fragmentation threshold), v_{frag} (speed of fragmentation), k (permeability), A_{spec} (specific surface area), η_{frag} (fragmentation efficiency), K_{ISR} (fracture toughness), v_p (mean p-wave velocity), v_s (mean s-wave velocity), A_{Vp} (Anisotropy of v_p), A_{Vs} (Anisotropy of v_s).

Table 1
Overview of the magma properties investigated and the experimental procedures employed

a) Properties investigated
1. Strength of porous magma against decompression, traction, and abrasion
2. Speed at which decompression-induced fragmentation propagates in magma
3. Permeability of porous magma to gas flow
4. Efficiency of decompression-induced fragmentation, i.e., the amount of fines generated per energy input
5. Velocity and velocity anisotropy of elastic waves in porous magma

b) Operative scheme
Sampling
Decimeter-sized, hand-collected or sawed from dome-derived lava and breadcrust bombs, derived from Vulcanian explosions
Pre-experiment characterization of samples
1. Porosity: Bulk density measured in the field and in the lab; open, closed, and total porosity measured by helium pycnometer (Kueppers et al., 2005)
2. Surface area of cylindrical specimens by BET (Scheu, 2005)
3. Petrograhic features observed under petrographic and SE microscopes
Experimental determinations
1. Shock-tube 1: Fragmentation threshold at high T & room T (Spieler et al., 2004b, Scheu et al., 2006b)
2. Shock-tube 2: Gas permeability under unsteady-state condition at room T (Mueller et al., 2005a)
3. Shock-tube 3: Speed of fragmentation at room T (Scheu et al., 2006b)
4. Abrasion tests at room T in a rotating cylinder
5. Fracture toughness tests at high T after ISRM
6. Standard, single-point flexural tests at room T
7. Elastic wave velocity measurements at high P and T in a multi-anvil apparatus (Scheu et al., 2006a)
Characterization of experimental products
1. Grain size by sieving and laser diffraction (Kueppers et al., 2006)
2. Surface area of experimentally generated pyroclasts by BET (Kueppers et al., 2006)

The total erupted volume during this eruption is estimated to be 2.1 km^3 (dense rock equivalent), 0.9 km^3 of which are represented by the dome in its today's state (Nakada et al., 1999b).

2.1. Unzen samples

All samples were collected from the deposits of the 1990 to 1995 eruption. The variably porous lavas originate from the dome, the breadcrust bombs from Vulcanian explosions (mainly 11th June 1991). The SiO_2 content is nearly constant at 65 wt.%. The lavas are porphyritic and contain 23–28 vol.% phenocrysts of plagioclase, hornblende, biotite and quartz. Plagioclase and hornblende exhibit the largest phenocrysts with average sizes of up to 5 mm (Fig. 2). The groundmass (rhyolitic glass of 78 to 80 wt.% SiO_2) exhibits varying degrees of crystallinity (33 to 50 wt.%), reflecting different discharge rates of magma (Nakada and Motomura, 1999; Noguchi et al., 2008-this issue).

Phenocrysts show a preferred orientation in dense samples (Fig. 2a). In the breadcrust bombs, the phenocryst content was found to be lower than in the extruded magma. In thin sections (Fig. 2b), a flow alignment of the microlites within the groundmass parallel to orientation of the phenocrysts is apparent. A typical vesicle structure found in the extruded magma, irrespective of its porosity, is shown in Fig. 2b. Therein the vesicles are irregularly shaped, often fringed, and hardly aligned. In dense samples, bubbles are often attached to phenocrysts (Fig. 2a, b). The breadcrust bombs show lower microlite content than the extruded magma. The vesicles within the breadcrust bomb are significantly smaller compared to the extruded magma, irregularly shaped and show incipient coalescence (Fig. 2c).

3. Density measurements

We performed density measurements in field and laboratory to account for variable porosity in space and time of ascending magmas. The field measurements were carried out in 2000 and 2001 on the 1990–1995 block-and-ash flow deposits with a technique following the Archimedean principle. This method quickly

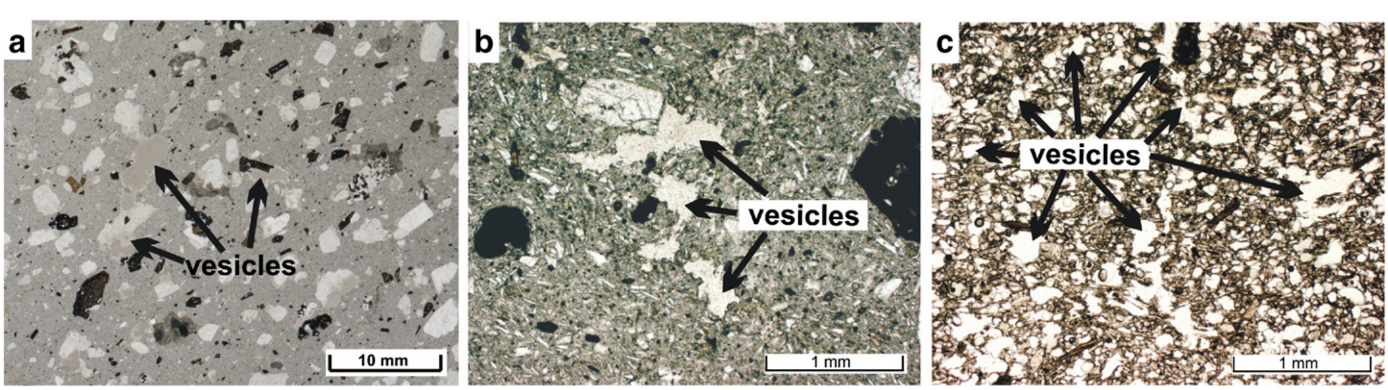

Fig. 2. Thin section images of Unzen dacite. (a) The largest phenocrysts reach about 5 mm and consist mainly of plagioclase and hornblende. Furthermore the phenocrysts are to some extent aligned. (b) Most of the samples exhibit irregular shaped, fringed vesicles, often attached to phenocrysts. A flow alignment of the microlites is discernable. (c) The interior of a breadcrust bomb. The vesicles are quite small and irregularly formed.