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Temperature dependence of elastic P- and S-wave velocities in porous Mt. Unzen dacite

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Abstract

Laboratory measurements of elastic properties of volcanic rocks are crucial for the modelling of volcano seismic activity. Compared to the large database reported in the literature for sedimentary, igneous and metamorphic rocks, the data set for volcanic rocks is limited and mostly restricted to basalts. Data for more silica-rich rocks are sparse. In particular, velocity data for silica-rich volcanic rocks measured at elevated temperature are lacking. We measured the elastic P- and S-wave velocities and the velocity anisotropy of porous dacitic rocks from Unzen Volcano, Japan, exhibiting an open porosity of 3.3 to 24.3 vol.%. The measurements were done at temperatures of up to 600 °C and confining pressures of 100 MPa, corresponding to depths of ~3000–4000 m. Samples with even higher porosities failed at the required pressures. The measurements were carried out in a cubic multi-anvil pressure apparatus, using the pulse transmission technique. In contrast to low-porosity magmatic and metamorphic rocks, the seismic velocities of the investigated volcanic rocks increased and the velocity anisotropies decreased with increasing temperature, due to further sample compaction. There is a close relationship between velocity, density and porosity. The higher the density (and the lower the porosity) the higher are the P- and S-wave velocities. These results can contribute to a better understanding of the propagation of seismic energy through the volcanic edifice.

Keywords: elastic wave velocities; high temperature; dacite; porosity; anisotropy; volcano seismology; Unzen Volcano

1. Introduction

Numerous laboratory measurements have been performed to determine the pressure dependence of ultrasonic wave velocities in rocks (Christensen, 1982; Gebrande, 1982). Experiments focussing on the temperature dependence of ultrasonic wave velocities in rocks are however rare. The small volcanic rock contribution to this already sparse data set consists mostly of measurements on basalts (Kern, 1982a). Significantly, no measurements have yet been performed on silica-rich volcanic rocks, although knowledge of how seismic energy propagates through silicic volcanoes is of paramount importance for hazard mitigation (Chouet, 1996; Neuberg, 2000); particularly as many explosive volcanoes are fed by silica-rich magma e.g. Mount St. Helen's (USA), Rabaul (Papua New Guinea), Unzen (Japan), and Soufrière Hills (Montserrat, West Indies). As volcanic rocks have undergone significant thermal shock and decompression upon eruption, the reconstitution of their original in situ properties requires measurements under relevant pressure and temperature conditions.

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Table 1
The density and porosity of the analysed samples at room temperature and atmospheric pressure

Sample	Bulk density (g/cm^3)	Matrix density (g/cm^3)	Powder density (g/cm^3)	Total porosity (vol.%)	Open porosity (vol.%)	Closed porosity (vol.%)	Closed/Open porosity (%)
15.9.97-b	1.93	2.54	25.93	25.93	24.30	1.63	6.71
MUZ 2000 B	2.10	2.55	19.32	19.32	17.58	1.74	9.92
MUZ 2000 E	2.18	2.55	16.31	16.31	14.50	1.81	12.47
MUZ 2000 C	2.28	2.56	11.97	11.97	10.94	1.03	9.43
Ensp2	2.42	2.60	7.28	7.28	6.92	0.36	5.15
MUZ 2000 A	2.49	2.59	4.08	4.08	3.71	0.37	9.99

The values are gained from volumetric and helium pycnometer measurements on therefore prepared cylindrical samples. To determine the closed porosity, the samples were milled to fine powder smaller than 63 μm in grain size.

Seismic velocities of silica-rich rocks measured under realistic conditions are required for numerical modelling of conduit processes and seismic wave propagation (Neuberg et al., 2000; Jousset et al., 2003; Sturton and Neuberg, 2003). Estimates of P- and S-wave velocities of silicic magma are further required to ameliorate the knowledge of the structure of many active volcanoes (as Rabaul (Papua New Guinea), Taupo Volcanic Zone (New Zealand), Nevado del Ruiz (Colombia)) derived by seismic tomography and the velocity structure (Finlayson et al., 2003; Londono and Sudo, 2003). The velocity model of Unzen was acquired during the "1995 Unzen seismic experiment" and consists of approximately 2-km-wide cubic blocks (Ohmi and Lees, 1995). This velocity model is very large scaled and can therefore only be used as a first-order assumption to model processes such as those inside the conduit.

In this paper, we present experimentally determined elastic P- and S-wave velocities and velocity anisotropies of porous dacitic rocks from Unzen Volcano, Japan. The experiments were performed in a cubic anvil pressure apparatus at pressures of up to 100 MPa and temperatures of up to 600 °C. These data are then evaluated and we discuss their implications for the interpretation of seismic data and refinements of models of seismic wave propagation in volcanic conduits.

2. Sample characterisation

We investigated six dacitic samples collected from Unzen Volcano, Kyushu, Japan. The last period of activity of Unzen Volcano took place from 1990 to 1995 (Nakada et al., 1999). During this time, 13 lobes were extruded and formed a complex dome. The exogenous and endogenous dome growth was frequently accompanied by block-and-ash flows and some minor explosive events (Nakada et al., 1999). During the mentioned period of activity, the SiO_2 content of lavas remained nearly constant around 65 wt.%. The lavas erupted are porphyritic and contain 23–28 vol.% phenocrysts of plagioclase, hornblende, biotite and quartz. Plagioclase and hornblende exhibit the largest phenocryst phases with average sizes up to 5 mm (Nakada and Motomura, 1999). The groundmass is composed of rhyolitic glass (78–80 wt.% SiO_2) with microlites of plagioclase, pargasite, pyroxene, Fe–Ti oxides, and apatite. The groundmass crystallinity appears to be related to the magma ascent rate, as it rises from 33 wt.% up to 50 wt.% with decreasing effusion rate (Nakada and Motomura, 1999).

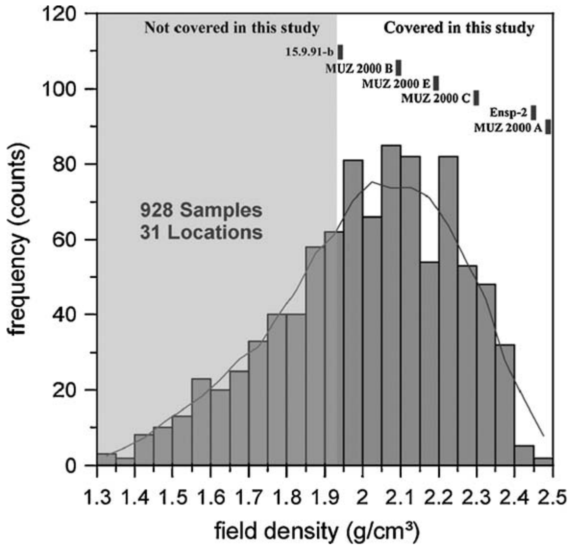

Fig. 1. The density bandwidth of the block-and-ash flow deposits of the 1990–1995 activity period of Unzen Volcano, Japan (grey bars and line) modified from Kueppers et al. (2005). The distribution consists of nearly 1000 single measurements carried out in the field. It ranges from 1.3 g/cm^3 to 2.5 g/cm^3 that corresponds to an open porosity range of 3 vol.% to 55 vol.%. Bread crust bombs, ejected during two explosive events, cover the range between 1.3 and 1.5 g/cm^3 (40 vol.%–55 vol.%). The black rectangles above the distribution represent the Unzen dacites analysed in this study. Their bulk density varies between 2.49 g/cm^3 and 1.93 g/cm^3, equivalent to an open porosity range of 3.7 vol.%–24.3 vol.% (see Table 1). More porous samples collapsed during initial pressurization, limiting the analysed density range to the above given values. The observed density distribution that we cover in this study enfolds the dense to the most abundant densities observed in the field. The area not covered in study is grayish colored.