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MFCI experiments on the influence of NaCl-saturated water on phreatomagmatic explosions

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Abstract

Molten–Fuel–Coolant Interaction (MFCI) experiments were performed using remelted foiditic rock samples from the West Eifel volcanic field (Germany). Two experimental series were carried out with one magmatic melt and two water compositions. Bi-distilled water was used in the first series (DW-1 to DW-5). In the second series (SW-1 to SW-5), the bi-distilled water was saturated (350 g L^{-1}) with sodium chloride (NaCl). For both experimental series the fragmentation history and the energy release were recorded and compared. The smallest particles (≤ 125 μm) were studied using scanning electron microscopy (SEM). Most MFCI experiments with bi-distilled water reached higher explosion intensities than the experiments with the saline water. This was accompanied by higher particle ejection velocities as well as the formation of more fine-grained and more interactive particles of angular shape. Additionally, the smallest artificial pyroclasts were examined by evolved gas analyses (EGA). The particles from the MFCI experiments with salt solutions are found to contain more sodium hydroxide (NaOH). These observations can be explained by thermodynamic arguments. In contrast to the MFCI experiments with pure water, an additional reaction occurs with saline water that results in evolution of hydrogen chloride (HCl) gas and leaves a residue of sodium hydroxide. The MFCI process with saline water consumes more enthalpy and Gibbs free energy, so that less energy is available for the explosion. With other sodium halides dissolved in the water (NaF, NaBr or NaI) the additional reaction can be predicted to have greater or lesser effects on phreatomagmatic explosions.

Keywords: volcanic MFCI; experimental volcanology; phreatomagmatic explosions; water–melt interaction; NaCl solution; thermodynamics; artificial pyroclasts

1. Introduction

Due to the presence of the hydrosphere, phreatomagmatic eruptions represent a common type of volcanic activity that can occur at all types of volcanoes. Several authors (e.g. Lorenz, 1973, Lorenz and Büchel, 1980; Wohletz and Sheridan, 1983; Lorenz, 1986; White, 1991) have pointed out that the formation of certain types of volcanoes, such as maars and tuff rings, is inevitably the

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result of the interaction between the ascending magmatic melt and external water (groundwater and surface water). Additionally, there are reports of phreatomagmatic activity at volcanoes with intense fumarolic activity and highly active hydrothermal systems, such as White Island volcano in New Zealand (Houghton and Nairn, 1991; Wood and Browne, 1996).

Phreatomagmatic explosions can be referred to as volcanic MFCIs. Two researcher groups have performed different Molten–Fuel–Coolant Interaction (MFCI) experiments with various substances aimed at understanding the explosive water–melt interaction (e.g. Wohletz, 1983; Wohletz and McQueen, 1984; Zimanowski et al., 1986, 1991, 1997a,b,c; Büttner and Zimanowski, 1998; Büttner et al., 2002). The present MFCI experiments consider the effects of a highly mineralised water solution on phreatomagmatic explosions for the first time.

2. Motivation and volcanological background

The motivation for this study is provided by the uneven distribution of maar volcanoes in the West Eifel volcanic field (Germany), as reported by Büchel (1993). The West Eifel volcanic field is known for the occurrence of maars and tuff rings (Lorenz and Büchel, 1980). Büchel (1993) considered the uneven distribution as an unexpected result, because it does not correspond with the geological basement and the associated availability of groundwater. Maar volcanoes predominate over scoria cones where there are poorly permeable Lower Devonian shales and siltstones. Maar volcanoes are less abundant where there are highly permeable rocks of Middle Devonian limestones and Triassic Bunter Sandstones (Büchel, 1993).

One possible explanation of this irregular distribution of the maars is the availability of different mineral waters in the area of the West Eifel. Büchel (1993) stated that maar volcanoes are dominant in regions with more highly mineralised waters. This suggests that strong mineralisation of water may have any influence on phreatomagmatic activity and/or the formation of maar volcanoes, respectively. The MFCI experiments presented here were set up to examine this type of water–melt interaction.

To simulate the magmatic melt in the MFCI experiments, a volcanic rock sample was chosen from a dyke of the scoria cone “In der Eyd” in the West Eifel volcanic field. This scoria cone represents a parasitic vent at the northern rim of the maar “In der Boos” (Grunewald, 2001). This locality is in the part of the West Eifel volcanic field where the geological basement consists of Devonian siltstones and schists. The sample represents an SiO_2-undersaturated foiditic rock. Chemical analysis of the rock was performed using a fully automated Philips PW 2400 X-ray spectrometer system with a rhodium X-ray source. The results of the major element analysis are listed in Table 1.

Table 1
Chemical composition and physical properties of the volcanic rock used for the MFCI experiments

Oxide	Weight percent	Oxide	Weight percent
SiO_2	42.19	MgO	9.85
TiO_2	3.02	CaO	14.93
Al_2O_3	12.03	Na_2O	2.89
Fe_2O_3	11.38	K_2O	3.33
MnO	0.19	P_2O_5	0.60

Physical property	Value
Phenocrysts	40–50 vol.%
Fine-grained groundmass	50–60 vol.%
Viscosity of the melt at 1300 °C	3 Pa s
Heat capacity, C_p, of the melt at 1300 °C	~1.4 J K^{-1} g^{-1}
Density of the melt at 1300 °C	~2.6 g cm^{-3}

From the volcanological point of view, viscosity is a key property of magmatic melts because of its effect on the behaviour of magma during volcanic processes. The viscosity of the remelted rock material used, for the current MFCI experiments, was measured using a rotation viscometer (Büttner et al., 2000). At a temperature of 1300 °C, the foiditic melt had a viscosity of 3 Pa s, which roughly represents the value for the melt during the MFCI experiments (Table 1).

3. Methods

The MFCI experiments were performed with the Thermal Explosion Experiment II set-up at the Physical-Volcanological Laboratory of the University of Würzburg, Germany. For detailed descriptions of the experimental device, the reader is referred to the publications of Zimanowski et al. (1997a) and Zimanowski (1998). The experimental run of an MFCI experiment is divided into four phases—the hydrodynamic mixing phase, the trigger phase, the fine-fragmentation phase and the vaporisation and expansion phase (Zimanowski et al., 1997a; Zimanowski, 1998; Büttner and Zimanowski, 1998). The procedure of an individual volcanic MFCI experiment is shown and briefly described in Fig. 1.

The experiments were carried out using a standard steel crucible, in which about 140 cm^3 of granulated rock was remelted. Earlier MFCI experiments (Zimanowski et al., 1997b; Büttner and Zimanowski, 1998) have shown that the explosion intensity strongly depends on the interacting water–melt mass ratio and the