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Correlations of volcanic ash texture with explosion earthquakes from vulcanian eruptions at Sakurajima volcano, Japan

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ABSTRACT

We compare the texture of volcanic ash with the maximum amplitude of explosion earthquakes (A_{eq}) for vulcanian eruptions from Sakurajima volcano. We analyze the volcanic ash emitted by 17 vulcanian eruptions from 1974 to 1987. Using a stereoscopic microscope, we classify the glassy particles into smooth surface particles (S-type particles) and non-smooth surface particles (NS-type particles) according to their surface conditions—gloss or non-gloss appearance—as an indicator of the freshness of the particles. S-type particles are further classified into V-type particles (those including vesicles) and NV-type particles (those without vesicles) by means of examinations under a polarized microscopic of polished thin sections. Cross-correlated examinations against seismological data show that: 1) the number fraction of S-type particles (S-fraction) has a positive correlation with A_{eq}, 2) the number ratio of NV-type particles to V-type particles (the N/V number ratio) has a positive correlation with A_{eq}, and 3) for explosions accompanied with BL-type earthquake swarms, the N/V number ratio has a negative correlation with the duration of the BL-Swarms. BL-Swarms refer to the phenomenon of numerous BL-type earthquakes occurring within a few days, prior to an increase in explosive activity [Kamo, K., 1978. Some phenomena before the summit crater eruptions at Sakura-zima volcano. Bull. Volcanol. Soc. Japan., 23, 53–64]. The positive correlation between the N/V number ratio and A_{eq} could indicate that a large amount of separated gas from fresh magma results in a large A_{eq}. Plagioclase microlite textual analysis of NV-type particles from five explosive events without BL-Swarms shows that the plagioclase microlite number density (MND) and the L/W (length/width) ratio have a positive correlation with A_{eq}. A comparison between textural data (MND, L/W ratio, crystallinity) and the result of a decompression-induced crystallization experiment [Couch, S., Sparks, R.S.J., Carroll, M.R., 2003. The kinetics of degassing-induced crystallization at Soufriere Hills volcano, Montserrat. J. Petrol., 44, 1477–1502.] suggests that a plagioclase microlite texture of volcanic ash from eruptions without BL-Swarms could be generated by a decompression of 100–160 MPa. If the MND is controlled by the water exsolution rate from melt, the positive correlation between the MND and A_{eq} may suggest that A_{eq} becomes large when the effective decompression is large and the water exsolution rate is high (from 6.2×10^{-5} to 1.9×10^{-4} wt.%/s). The estimated magma ascent rate ranges from 0.11 to 0.35 m/s, which is one order of magnitude faster than that of an effusive eruption, and one to three orders slower than those for a (sub-) plinian eruption. This suggests that the ascent rate of magma plays an important role in the occurrence of vulcanian eruptions. We propose a simple model for vulcanian eruptions at Sakurajima volcano that takes into account the correlation between the S-fraction and A_{eq}.

1. Introduction

Studies based on geophysical observations, such as seismological, infrasonic and ground deformation observations may help to elucidate the location and magnitude of overpressure sources (e.g., Ripepe et al., 1996; Chouet et al., 2005; Ohminato et al., 2006) and conduit geometry (e.g., Baker and Malone, 1991; Castellano et al., 1993; Iguchi, 1994; Longpre et al., 2007) related to volcanic eruptions. At Sakurajima volcano, earthquakes and ground deformation associated with vulcanian eruptions have been used for modeling the mechanical process of an eruption (e.g., Tameguri et al., 2002; Iguchi et al., 2007). Although seismic signals and ground deformation are generated by macroscopic movements of magma, there may be some magma movements that do not generate earthquakes or ground deformation. In addition, there is no general tool that quantitatively relates observational data with the ascent rate or decompression rate of magma. Therefore, we need direct information on the ascent rate or decompression rate experienced by erupted materials.

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Textural and compositional analysis of volcanic product has revealed the behavior of magma in an erupting conduit (e.g., Polacci et al., 2001; Kennedy et al., 2005; Noguchi et al., 2006). For instance, Taddeucci et al. (2004a) inferred conduit processes for different types of explosive activity at Mt. Etna by examining the crystal size distributions (CSDs) of volcanic ash. However, the understanding resulting from these studies of the behavior of magma during eruptions is still qualitative.

Some recent studies have carried out textural analyses with special reference to geophysical observations (Wolf and Eichelberger, 1997; Hammer et al., 1999, 2000). These studies found the relation between the textural features of eruptive products and corresponding geophysical observations, such as number of days since the onset of activity (Wolf and Eichelberger, 1997), repose interval (Hammer et al., 1999), and magma discharge rate (Hammer et al., 2000). However, such quantitative relations between the textural features and geophysical data have not been understood from the viewpoint of more essential factors controlling textural features, that is, the water exsolution rate or ascent rate.

Recently, some studies have examined the physical meaning of textual data that give quantitative constraints on magma movement and pre-eruptive conditions. Bubble number density records the decompression rate of magma at the bubble nucleation depth (Toramaru, 2006). Microlite number density (MND) is an indicator of the water exsolution rate of magma at the microlite nucleation depth under specific conditions (Toramaru et al., 2008) that were used to quantify the magma ascent process in the dome-forming eruptions at Unzen (Noguchi et al., 2008). It has been found that the crystallinity of the erupted product reflects the amount of decompression and crystallization time (Hammer and Rutherford, 2002; Couch et al., 2003).

In this paper, in order to obtain quantitative information on magma ascent such as decompression and ascent rate, we examine textural and compositional data on volcanic ash, and compare them with seismic data. First, we present a classification of volcanic ash based on surface features of the particles and vesicle texture for a variety of eruption intensities. Second, we show the result of quantitative microlite textural analysis. Third, we examine correlations between the fraction of a specific type of ash and microlite textural analysis and the maximum amplitude of an explosion earthquake (A_{eq}). Fourth, we discuss the origin of such correlations by considering the microlite crystallization process caused by magma ascent and water exsolution on the basis of experimental results obtained by Couch et al. (2003) and the MND water exsolution rate meter (Toramaru et al., 2008). Finally, we propose a simple model that explains the correlation between ash features and A_{eq}.

2. Recent vulcanian activity at Sakurajima volcano

Sakurajima volcano, located in southern Kyushu, is one of the most active andesitic volcanoes in Japan. The volcano consists of two main cones (Kitadake and Minamidake) and some parasitic domes. It has an elliptical-shaped base with N–S and E–W minor and major axes of 9 and 12 km, respectively. The height of the summit is approximately 1000 m above sea level. The Minamidake summit crater has displayed eruptive activity since October 1955, with more than 7800 explosions of various intensities. The total mass of ash emitted from 1978 to 2000 amounts to approximately 2×10^8 tons (Ishihara, 2000).

The eruptions at the summit crater are mainly vulcanian in nature. The explosions emit a mixture of pyroclast and gas, and are accompanied by explosion earthquakes and intense air shocks. Seismic observations and geophysical surveys have been conducted by Sakurajima Volcano Research Center (SVRC), Kyoto University. In Sakurajima volcano, according to a classification by Minakami (1974), A-type, B-type, explosion earthquakes and volcanic tremors are recognized (Iguchi, 2005). The waveform of an A-type earthquake contains high-frequency components with clear P and S phases, similar to local tectonic earthquakes. B-type earthquakes are dominated by a low-frequency waveform component and are categorized into BL-type (dominant frequency: 1 to 3 Hz) and BH-type (dominant frequency: 4 to 7 Hz) earthquakes (Iguchi, 1994). Explosion earthquakes also are dominated by a low-frequency component, indicating a clear first motion of wave with a higher amplitude than a B-type earthquake. The waveforms of an explosion earthquake comprise a P-wave first motion, following a dilatational motion with larger amplitude, and then the largest amplitude motion (LP phase; Tameguri et al., 2002). The hypocenters of the explosion earthquakes are located 1 to 3 km beneath the summit crater, and the hypocentral zone outlines a conduit zone with a radius of about 200 m. Most hypocenters of BL-type and BH-type earthquakes are located within this conduit zone, with hypocentral depths slightly different betweenthe BL-type (2 to 3 km) and the BH-type (2 to 3.5 km) earthquakes (Iguchi, 1994), whereas those of the A-type earthquakes are

Table 1a
Samples used in this study and seismological data. The symbols ○ and × represent the presence and absence of BL-Swarms, respectively.

Sample name	Explosion date (year-month-day-time)	Sampling point (distance and direction from crater)	Maximum amplitude of explosion earthquake (μm)	BL-Swarms Presence	Start time (year-month-day-time)	End time (year-month-day-time)	Duration time (minute)
74-12-27	74-12-27 07:29	5.5 km, WNW	12.5	○	74-12-24 ca.08:00	74-12-26 ca.13:00	3180
74-12-31	74-12-31 12:14	4.5 km, E	30	×	×	×	0
75-3-2	75-3-2 20:08	4.5 km, E	10	×	×	×	0
76-5-25	76-5-25 16:57	5.8 km, NE	62.5	×	×	×	0
76-5-26	76-5-26 19:59	5.5 km, WNW	17.5	×	×	×	0
76-9-1	76-9-1 23:09	4.5 km, E	17.5	×	×	×	0
77-8-11	77-8-6 1:37	4.5 km, E	17.5	Unknown[a]	Unknown	Unknown	Unknown
80-4-26	80-4-26 19:02	Unknown	12.5	Mixed[b]	×	×	Unknown
81-11-22	81-11-22 13:22	3.0 km, S	25	○	81-11-17 2:27	81-11-17 8:14	347
82-8-21	82-8-21 06:46	4.5 km, E	35	×	×	×	0
83-5-22	83-5-22 12:37	4.5 km, E	10	○	83-5-20 ca.19:15	83-5-21 ca.06:01	645
83-6-22	83-6-22 16:45	2.7 km, NW	5	×	×	×	0
83-8-22	83-8-22 13:06	4.5 km, E	25	○	83-8-20 ca.06:00	83-8-20 ca.13:09	430
84-2-4	84-2-4 21:16	4.5 km, E	27.5	○	84-2-1 ca.03:15	84-2-1 ca.07:45	270
84-6-4	84-6-4 3:12	5.5 km, WNW	20	Mixed[b]	×	×	Unknown
85-9-4	85-9-4 11:27	4.8 km, NNW	40	○	85-8-31 ca.21:00	85-9-1 16:00 to 17:00	1140[c]
87-11-17	87-11-17 20:56	4.5 km, E	20	○	87-11-15 ca.16:00	87-11-16 ca.21:00	1740

[a] With or without BL-Swarms is not confirmed due to loss of continuous seismograph record.
[b] Explosion earthquakes and BL-type earthquakes occur simultaneously.
[c] Minimum value of duration time of BL-Swarms.