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Changes to the volcanic outgassing mechanism and very-long-period seismicity from 2007 to 2011 at Mt. Asama, Japan

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ABSTRACT

Volcanic gases can provide significant information on the state of magma, which is important for interpreting and predicting volcanic activity. We present a study of the seismicity and volcanic gases from Mt. Asama, Japan from 2007 to 2011 to elucidate the change in the mechanism of volcanic gas supply for very-long-period (VLP) seismic events. Two types of degassing occur at Mt. Asama: persistent degassing and a gas burst (ash-free eruption) following a VLP seismic event. We used the linear relationship between the seismic moment and sulfur dioxide (SO_2) emissions, and seismic records to estimate the quantity of SO_2 gas in the ash-free eruption, which causes the VLP seismic events. The amount of SO_2 and volcanic gas composition data were used to calculate the amount of volcanic gases, including H_2O, CO_2, and other species. We compared the volcanic gas emission rates of ash-free eruptions (eruptive gas emission rates) and total volcanic gas emission rates including the persistent degassing. The ratio of the eruptive gas emission rate to the total gas emission rate (eruptive/total gas ratios) showed a drastic change with eruption. An increase occurred immediately before the 2008 and after the 2009 eruptions. The VLP seismic events are likely caused by sudden outgassing at a shallow depth that is induced by the propagation of the gas phase expansion and rupture. We suggest that the rates of sudden outgassing are controlled by the distribution of gas phases in the conduit. The variability of the eruptive gas emission rates suggests changes in the gas phase distribution in the conduit.

1. Introduction

The volatile components dissolved in magmas play an important role in volcanic activity, and the exsolution of volatiles provides a driving force for explosive eruptions. Volcanic gases can provide significant information on the state of magma, for example, the amount of outgassed magma and the magma degassing pressure. Observations of volcanic gas have been made at many volcanoes to monitor volcanic activity. Variations in the composition and emission rates of volcanic gases during active and inactive periods at volcanoes were reported (e.g., Oppenheimer et al., 2003; Christopher et al., 2010; Holland et al. 2011), suggesting changes in the degassing mechanisms of volcanoes. It is important to quantify the amount of volcanic gas that is emitted as persistent degassing and that which is released during eruptions to elucidate the degassing mechanism. However, the amount of volcanic gas emitted by eruptions has been examined from the ground in only a few studies (Fischer et al., 2002; Mori and Burton, 2009; Kazahaya et al., 2011) because measuring volcanic gas emission rates during eruptions is difficult. The combination of volcanic gas studies with other geophysical approaches is desirable to provide insight into the degassing mechanism, because volcanic gas exhalation frequently shows a correlation with geophysical phenomena (e.g., Fischer et al., 1994; Young et al., 1998; Watson et al., 2000). Links between volcanic gas emissions and geophysical data streams (e.g. infrasound and seismicity) for discrete eruptive events were found by previous studies (e.g. Dalton et al., 2010; Kazahaya et al., 2011; Nadeau et al., 2011), which are important for interpreting volcanic activity.

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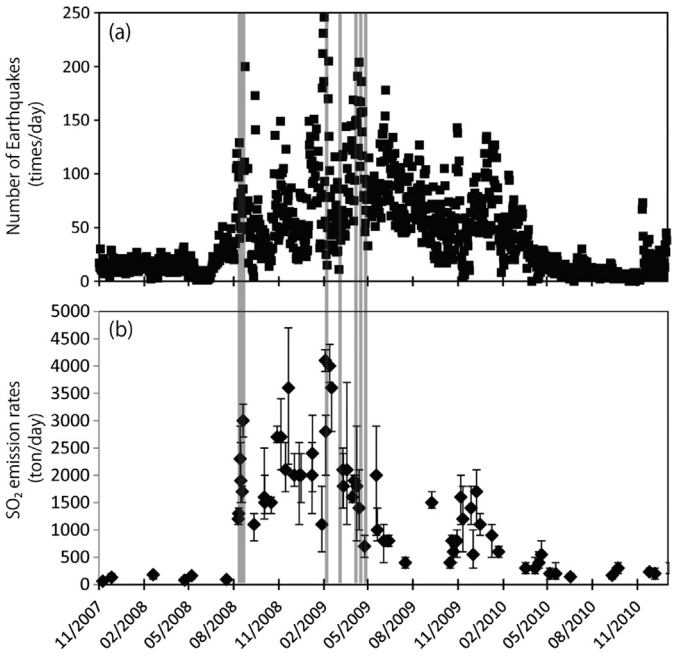

Fig. 1. Degassing and seismic activities from Nov. 2007 to Jan. 2011 at Mt. Asama, Japan. (a) Temporal variations in the numbers of low-frequency earthquakes from Ohwada et al. (2013). (b) Sulfur dioxide emission rates observed using UV remote sensing techniques reported by Ohwada et al. (2013). Vertical grey lines indicate the periods of eruptions.

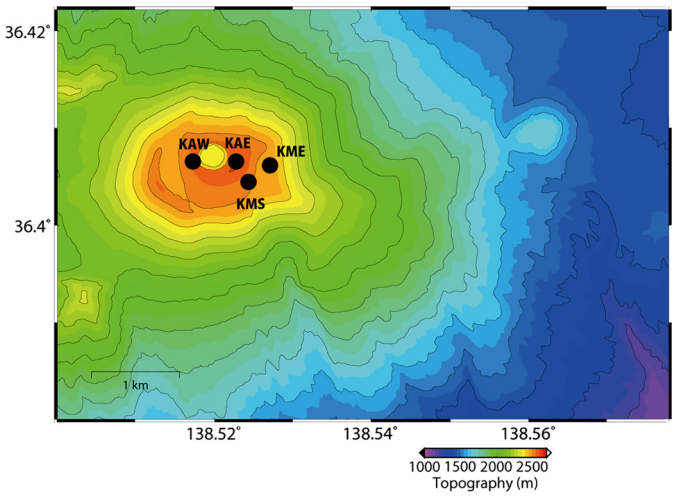

Fig. 2. Map of Mt. Asama. The solid circles show the locations of the seismic observation sites. The volcanic gas composition was measured using the Multi-GAS instrument on the crater rim on June 3, 2009.

Very-long-period (VLP) seismic events with durations of 5–30 s are thought to be excited by the movement and volumetric changes of magmatic fluids (e.g., Chouet et al., 2010). VLP seismic events are commonly observed at volcanoes with vigorous degassing. They have been modeled using pressure change in the conduit caused by gas slug ascent at Stromboli, Italy (Chouet et al., 2003). Similar VLP seismic source models have been examined in laboratory experiments (e.g., James et al., 2004) and numerical simulations (O'Brien and Bean, 2008). These results suggest that an expansion of gas slug within the conduit can generate VLP seismic events.

VLP seismic events are related to different volcanic activities (e.g., Waite et al., 2013). At Mt. Asama, Japan, a gas burst was observed after a VLP seismic event as reported by Kazahaya et al. (2011). They measured the amount of SO_2 discharged by a single gas burst and that of persistent degassing (persistent SO_2 emission), indicating the degassed magma amount associated with the single gas burst and a persistent magma outgassing rate, respectively. The amount of SO_2 discharged by the gas bursts associated with the VLP seismic events were one to three orders of magnitude greater than those for discrete eruptions at Stromboli, Italy (Mori and Burton, 2009), suggesting that the quantity of magma related to the gas bursts at Mt. Asama was larger than those related to the discrete eruptions at Stromboli. Because of the significant quantity of magma associated with the gas bursts following the VLP seismic event, hereafter, we refer to the gas burst as "ash-free eruption" and the amount of SO_2 discharged with the VLP seismic events as "eruptive SO_2 emission". The ratio of the eruptive SO_2 emission to the total SO_2 emission (i.e., sum of eruptive and persistent SO_2 emissions) was calculated as 16% on June 2, 2009 (Kazahaya et al., 2011). We would expect some changes in the ratios caused by volcanic activities because 1) SO_2 emission rates fluctuate markedly from a few hundred to several thousand tons per day, showing a good correlation with the number of low-frequency earthquakes (0.5–2 Hz) (Ohwada et al., 2013) (Fig. 1) and 2) VLP seismicity varies with the intensity of volcanic activities (Yamamoto et al., 2005) at Mt. Asama. Long-term variability in the contribution ratios is likely to indicate change in the outgassing mechanism that causes VLP seismic events; however, there have been no studies to examine the long-term changes because it is difficult to observe all ash-free eruptions. At Mt. Asama, Kazahaya et al. (2011) revealed a linear relationship between VLP seismic moments and eruptive SO_2 emissions. We apply this linear relationship to estimate the eruptive SO_2 emission from VLP seismic moment data by assuming that the linear relationship is invariant.

In this study, we estimated eruptive SO_2 emission rates from VLP seismic data and the linear relationship at Mt. Asama, Japan from 2007–2011. The ratios of the eruptive to total gas emission were calculated to estimate the proportion of volcanic gas, which causes the VLP seismic events. Variations in these time series were compared with the eruptive activities to elucidate the change in the outgassing mechanism of the volcano.

2. Mt. Asama

Mt. Asama, located in central Japan, is an active andesitic stratovolcano (Fig. 2). It has a summit elevation of 2568 m above sea level (a.s.l.). The summit has a crater approximately 450 m in diameter and 250 m deep. The volcanic activity of Mt. Asama is characterized by extensive degassing and seismic activity (Fig. 1). The volcanic SO_2 emission rates have been recorded since 1972 (Ohwada et al., 2013) and VLP seismic events have been observed since 2003 by broadband seismometers installed at the crater rim (Yamamoto et al., 2005). Moderate Vulcanian eruptions occurred in 2004 and minor eruptions occurred on August 10, 11, and 14, 2008. The seismic activity and SO_2 emission rates increased after June and August 2008, respectively (Fig. 1). After the 2004 eruption, the degassing and seismic activities were high. In February 2009, the SO_2 emission rates and the number of earthquakes reached 4000 ton/day and 250/day, respectively; and a moderate eruption occurred forming a vent approximately 30 m wide at the crater bottom. After the first 2009 eruption, the SO_2 emission rates and the number of earthquakes decreased and minor eruptions continued until May 2009.

Maeda and Takeo (2011) conducted seismic observations at Mt. Asama using 14 broad-band seismometers and obtained sufficient data for waveform inversion analysis from September to December 2008. They revealed that the VLP seismic source was located in the northern part of the crater at depths of 100–150 m from the crater bottom. The principal value ratios of the moment tensor solutions were calculated as 5:3:2, indicating a combination of