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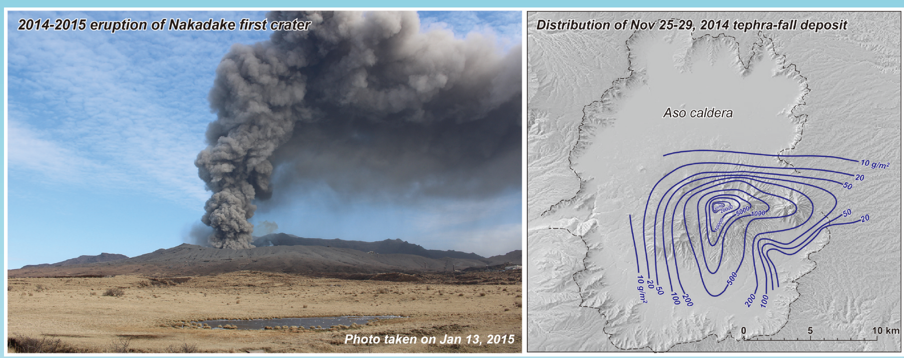
Advancement of our knowledge on Aso volcano: Current activity and background



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PREFACE

Open Access

Special issue "Advancement of our knowledge on Aso volcano: current activity and background"

Takahiro Ohkura[1*], Akihiko Yokoo[1], Yasuo Miyabuchi[2], Jerry Fairley[3], Corrado Cigolini[4] and Valerio Acocella[5]

Introduction

Aso volcano is one of the most active volcanoes in Japan located in the volcanic front on Kyushu-Ryuku Island arc. Central cones including the active Nakadake cone located inside the caldera which was formed by four pyroclastic flow eruptions. The Nakadake cone hosts a hot and acid crater lake and frequent phreatic-to-magmatic eruptions. From gigantic caldera-forming eruptions to fumarolic activities, Aso volcano provides us with a wide-range of research subjects which improve our understandings of the volcanic system.

The most recent magmatic eruptions at Aso volcano characterized by Strombolian explosions and continuous ash venting, began on 25 November 2014, after about 20 years of dormancy. In late 2015 and 2016, violent phreatic and phreatomagmatic explosions occurred repeatedly. This special issue focuses on scientific researches at Aso volcano completed before, during, and after the 2014–2016 eruptive activities. In total, 19 articles were published in the special issue; these are described accordingly with the investigating methods.

Geology, petrology, and material sciences

In the special issue, four articles are published on the geological, petrological, and mineralogical aspects of eruptions at Aso. A frontier letter by Miyabuchi and Hara (2019) presents the distribution, discharged mass, and components of tephra-fall deposits during the 2014–2015 eruption of the Nakadake first crater at Aso volcano. The tephra-fall deposits consisted of glass shards, crystal, and lithic grains. In the November 25–27, 2014 ash-fall deposits, lithic fragments, which are interpreted to be derived from lavas or pyroclasts of previous eruptions, were dominant (59–68%). Thereafter, the proportion of glass shards, which are probably juvenile materials of newly ascending magma, gradually increased with time, and the December 21–23, 2014 ash contained abundant glass grains (63%). The proportions of glass shards ranged from 29 to 50% until February 25, 2015. Subsequently, they decreased with time and reached 14% on March 17. Afterward, the proportions increased again prior to April 27 and ranged between 20 and 30% in May 2015. From November 25, 2014 to the end of January 2015, the cumulative erupted mass increased at a high discharge rate (2.2×10^4 tons/day). After February 2015, the cumulative erupted mass decreased to a low rate of 0.6×10^4 tons/day, although this rate rose slightly in March and late April 2015. The total erupted tephra mass was 2.1×10^6 tons (1.2×10^4 tons/day), which was less than the tephra deposits of previous activities that have occurred within the past few decades.

Namiki et al. (2018) conducted three series of measurements for high-porosity scoriae and ash ejected from the Nakadake crater during magmatic eruption in 2014–2015. From their results of measurements, Namiki et al. (2018) elucidated the eruptive conditions causing such ash emission and generation of scoriae and inferred the sequence of an eruption as follows. Cooling of the uppermost part of the high-porosity foam in the conduit causes fracturing of the magma foam, which creates the glassy brown ash to be ejected. Some part of the brown ash falls back onto the top of the high-temperature foam and is altered to black ash. The ash particles are initially mobile, and the ash layer has a large permeability. Ultimately,

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the bottom of the ash layer may undergo sintering and its permeability is reduced. The underlying foam layer is pressurized and ash eruption occurs. Once the debris layer at the top of the magma foam is removed, the underlying magma foam erupts as scoriae.

In Saito et al. (2018), petrological observations and chemical analyses on scoriae and related melt inclusions in mineral phases were used to investigate the magma ascent and eruption processes of the 1979, 1989, and 2014 eruptions of Nakadake crater, Aso volcano. The whole-rock analyses of the scoria produced by the November 26–27, 2014 eruption indicated that they are andesite in composition and identical to those of the 1979 and 1989 eruptions. Thermometry using the chemical composition of the groundmass and the rims of the phenocrysts indicated that the temperature of the 2014 magma was 1042–1092 °C. Melt inclusions in plagioclases, clinopyroxenes, and olivines in the 2014 scoria had an andesite composition similar to that of the groundmass. The volatile content of the melt inclusions was 0.6–0.8 wt% H_2O, 0.003–0.017 wt% CO_2, and 0.008–0.036 wt% S. The variation in CO_2 and S content of the melt inclusions was not correlated with the K_2O content, suggesting that the magma degassed as pressure decreased. Melt inclusions in plagioclases, clinopyroxenes, and olivines from the 1979 and 1989 scoria had similar major elements and volatile content to the 2014 eruption specimens. The similarity in chemical composition of both the whole-rock and melt inclusions among all samples suggests that the magmas of these eruptions were derived from the same magma chamber. The gas saturation pressure estimated from the H_2O and CO_2 contents of the 1979, 1989, and 2014 scoria ranged from 18 to 118 MPa, corresponding to depths of 1–4 km. Based on the bulk sulfur content of the magma and the SO_2 flux between January 2014 and December 2017, the amount of degassed magma over that period was estimated to be the equivalent of 1–3 km^3 of dense rock. The estimated volume was more than 600 times larger than that of eruptive products during the same period. This suggests degassing of magma in the chamber associated with magma convection within a conduit.

Ishibashi et al. (2018) investigated chemical compositions of amphibole phenocrysts in pyroclasts collected from the initial and largest pyroclastic unit(4I-1) of the Aso-4 caldera-forming eruption occurred at ~90 ka to clarify their crystallization conditions and pre-eruptive magmatic processes. The results suggest the following: (1) most of the amphibole phenocrysts coexisted with silicate melt with 66–72 wt% SiO_2 and temperatures of 910–950 °C, whereas some amphiboles crystallized from more mafic and higher-T melt; (2) the amphibole phenocrysts are in thermal and chemical disequilibrium with the host 4I-1 melt, indicating that they were incorporated into the melt immediately prior to eruption; and (3) amphibole phenocrysts crystallized at a depth of ~13.9±3.5 km, which coincides with the depth of the present low-velocity zone beneath the volcano, implying that the depth of the post-caldera magma plumbing system is strongly influenced by a relic collapsed magma reservoir related to the most recent caldera-forming eruption.

Geophysical research

There are seven articles in the special issue on geophysical studies. In Kanda et al. (2019), AMT data acquired between 2004 and 2005 were reanalyzed using a recently developed 3-D inversion code incorporating detailed topography into the model in order to estimate the detailed shallow resistivity structure of Aso volcano. A highly conductive zone is observed beneath the active crater down to a depth of approximately 300 m. Based on the recent findings regarding the shallow hydrothermal system of the volcano such as Ichimura et al. (2018), this conductive zone could be interpreted as formed by highly conductive acidic fluids filling a fractured region. This view modifies the past interpretation made based on the 2-D models and promotes understanding of fluid behavior beneath the active crater. And this 3-D model was used as an initial model in Minami et al. (2018).

Huang et al. (2018) derived crustal Vs structures beneath Aso caldera using analyses of ambient seismic noise signals. Daily CCFs of seismic station pairs were calculated and then CCFs were stacked monthly, to obtain Rayleigh wave phase velocity dispersion curves. And 1–5-s phase velocity maps were constructed with 0.05° grid spacing. The post-caldera central cones are characterized by high velocities from the surface to a depth of 1 km. In the center of the post-caldera central cones, low velocities prevail at the surface and extend to major anomalies at depths of 1–2.5 km. These low-velocity anomalies can be assumed to be shallow hydrothermal reservoirs that might be related to surface geothermal activity. The low velocities identified at depths of 5–6 km beneath the post-caldera central cones might indicate the top of magma chambers. The low-velocity belts situated at 2.5–5 km depths are likely pathways for the transfer of hydrothermal fluids, volcanic gases, or melting magma to the surface.

Ichimura et al. (2018) estimated the source locations of continuous tremors at Aso volcano over a 2-month period preceding ash–gas emissions in January 2014. During the period from December 2013 to January 2014, a significant variation in the amplitude of continuous seismic tremors corresponding to surficial volcanic activity was observed around the Nakadake crater. The tremor source locations were estimated by a three-dimensional grid search using the tremor amplitude ratio of 5–10 Hz band-pass filtered waveforms. The estimated source locations were distributed in a roughly cylindrical region (100–150 m in diameter) ranging from the ground surface to a depth of 400 m just beneath the crater. Migration of the estimated source location was also identified and was associated with changes in volcanic activity.

Minami et al. (2018) reported results of ACTIVE during the previous magmatic eruption period of Aso volcano (November 2014 to May 2015). 3-D inversion using a finite-element method of the ACTIVE data sets from August 2014 and August 2015 succeeded in revealing temporal variations in the resistivity structure between the period before and that after the magmatic eruptions as follows: a noticeable decrease in resistivity at an elevation of ~ 1050 m on the western side of the crater, and an increase in resistivity at elevations of 750 to 850 m, not only below the crater bottom but also extending outside of the crater. The increase in resistivity can be ascribed to a decrease in the amount of conductive groundwater in the upper part of an aquifer located below the elevation of 800 m, while the decrease in resistivity implies that enhanced fluid temperature and pressure changed the subsurface hydrothermal system and formed a temporal fluid reservoir at the shallow level during the magmatic eruption period.

Tsunematsu et al. (2019) conducted a video camera observation of the Strombolian eruptions at Aso volcano in 2015 and analyzed the video images to investigate the gas flow effect on the particle transport of large pyroclasts (> 10 cm). Using the obtained trajectory data, the features of Strombolian activity such as ejection velocity, explosion energy, and particle release depth were investigated. The gas flow velocities were estimated by comparing the simulated and observed trajectories. The range of the ejection velocity of the observed eruptions was 5.1–35.5 m/s, while the gas flow velocity, which is larger than the ejection velocity, reached a maximum of 90 m/s, with mean values of 25–52 m/s for each bursting event. The particle release depth, where pyroclasts start to move separately from the chunk of magmatic fragments, was estimated to be 11–13 m using linear extrapolation of the trajectories. Although these parabolic trajectories provide us with an illusion of particles unaffected by the gas flow, the parameter values show that the particles are transported by the gas flow, which is possibly released from inside the conduit.

Ishii et al. (2019) analyzed characteristic VLP signals, eruption earthquake signals, and infrasound signals accompanying Strombolian explosion events at Aso volcano in late April 2015. The explosion depth and ascent velocity of a gas phase in the conduit were estimated using the differences in the seismo-acoustic signal arrival times. The obtained depth was < 400 m and the ascent velocity of the gas phase was estimated to be 1–160 m/s. This velocity is too fast to assume the migration of a gas slug through the conduit. The ascent velocity of a slug from theoretical and experimental approaches cannot exceed 7.5 m/s under the conditions present at Aso volcano. To explain the estimated values, they proposed a revised model describing the migration of the gas phase via a more complicated mechanism, such as annular flow.

Yokoo et al. (2019) provides detailed descriptions of monochromatic infrasound waves observed at Aso volcano. Throughout the entire eruption period in 2014–2015, when both ash venting and Strombolian explosions occurred, monochromatic infrasound waves were observed nearly every day. The source location of the signals was highly stable at the active vent. Although the peak frequency of the signals (0.4–0.7 Hz) changed over time, the frequency exhibited no reasonable correlation with the eruption style. Based on finite-difference time-domain modeling using 3-D topographic data of the crater during the eruption (March 2015), the propagation of infrasound waves from the conduit was calculated assuming that the shape of the conduit was a simple pipe. The peak frequency of the observed waveforms was well reproduced by the calculation, while the length of the pipe markedly defined the peak frequency. By replicating the observed waveform, the gas exhalation with a gas velocity of 18 m/s occurred at 120 m of depth in the conduit.

Geochemical research

Three articles on geochemical research were published in this special issue. A frontier letter by Shinohara et al. (2018a), reports chemical compositions of the salt fallouts observed during the intensive gas emission and ash eruption stages of the Nakadake crater of the Aso volcano. Spherical hollow salt shells were observed on several occasions during and shortly after the weak ash eruptions. Most of the salt fallouts have composition similar to those of the dried crater lake water samples and are quite different from those of the ash leachates. The hollow structure of the shells suggests that they were formed by the heating of hydrothermal solution droplets suspended by a mixed stream of gas and ash in the plume. The salt shells indicate a close distribution of the hydrothermal system surrounding the erupting vent, even during the continuous magmatic eruption stage.

Morita et al. (2019) conducted continuous monitoring of soil CO_2 flux in the flank of Nakadake cone, Aso volcano, from January 2016 to November 2017. After applying a multivariate linear regression analysis, the obtained time series of soil CO_2 flux presented some anomalous peaks in both the active and calm periods. Careful comparison of the anomalous peaks with the environmental parameters revealed that most of the anomalous peaks were likely due to an increase in wind speed and/or a decrease in barometric pressure. However, the anomaly after the 8 October 2016 eruption could not completely be explained by the variations in the environmental parameters and coincided with increases in seismic amplitude and plume SO_2 flux. This anomaly was possibly attributed to an increase in magmatic CO_2 flux. These findings emphasized the importance of careful statistical treatment of the soil CO_2 flux data by excluding the influences of the environmental parameters at each measurement site.

Shinohara et al. (2018b) reported gas composition measurement obtained by means of multi-GAS, which was collecting data during the 2014–2015 eruptive phase, as well as the quiet period preceded the above events. Volcanic gas composition during the eruptive period is characterized by rapid and large variation. In particular, the CO_2/SO_2 and SO_2/H_2S varied in the rages of 1–8 and 3–300 during the ash eruption with intermittent Strombolian activity. The variation shows a well-constrained correlation between two end-member compositions: one is $CO_2/SO_2 = 8$ and $SO_2/H_2S = 3$ and the other is $CO_2/SO_2 = 1.5$ and $SO_2/H_2S = 300$. The large variation and the negative correlation in compositions are attributed to a marked difference in the degassing pressure with reaches two orders of magnitude, such as 20 and 0.2 MPa; the gases with the large CO_2/SO_2 and the small SO_2/H_2S are related to high-pressure conditions. The rapid and large compositional variation suggests frequent ascent of bubbles formed at various depth during the eruption. The maximum CO_2/SO_2 decreased with the intensity of the eruption suggesting a decline of the bubbles derived from a large depth. With time, H_2O/SO_2 increases from 30 to >60, suggesting an increase in a hydrothermal contribution at lower depth.

Remote sensing

Four articles in the special issue are based on remote-sensing analysis. Cigolini et al. (2018) analyzed the thermal signature of Nakadake crater of Aso volcano during unrest episodes by combining the MODIS-MIROVA data set (2000–2017) with high-resolution images (LANDSAT 8 OLI and Sentinel 2) together with ground-based thermal observations (2013–2017). During fumarolic activity, VRP detected by both of the satellite and ground observation was below 0.5 MW and reached 2–2.8 MW with increasing activity. Prior, during, and after the major Strombolian explosions, satellite VRP data are above 10 MW, reaching peak values of 15.6 MW. After the volcano re-entered the phreatic phase, satellite data processed by MIROVA exhibit very few thermal alerts, whereas ground-based measurements initially were fluctuating around 1 MW. They provided VRP threshold values that define the transition from high fumarole activity, through phreatic–phreatomagmatic activity, to a Strombolian phase at active Nakadake crater.

Morita (2019), using land observation data of the plume height and satellite observation data of SO_2 mass, reports on the degassing activity before the 8 October 2016 phreatomagmatic eruption of Aso volcano. In this study, the temporal variations of the plume height, the SO_2 mass, and ground-based SO_2 flux during 6 months before the eruption were investigated. The results show that the maxima and the increasing trends in the above parameters, respectively, occurred about 2 months and 6 days before the eruption. This result indicates that the degassing system had been stable during 6 months before the eruption and that the accumulation of volcanic gas in the conduit, since August might trigger the phreatomagmatic eruption. It was shown that these techniques can be effective to monitor the degassing activity of the volcanoes.

Ishii et al. (2018) used the Ash RGB images from Himawari-8 to detect and track SO_2 cloud from a phreatomagmatic eruption of Aso volcano on October 8, 2016. The Ash RGB is a composite image of three observation bands of Himawari-8 (RED: brightness temperature difference between 12.4 and 10.4 μm, GREEN: brightness temperature difference between 10.4 and 8.6 μm, and BLUE: 10.4 μm), and can discriminate SO_2 clouds and volcanic ash clouds from meteorological clouds. They could estimate the height of the SO_2 cloud by comparing the Ash RGB images and simulations of the JMA Global Atmospheric Transport Model: the estimated height of the SO_2 cloud was 7–13 or 7–14 km. Using the cloud height and eruption duration, the total mass of volcanic ash from the eruption was estimated to be $6.1–11.8 \times 10^8$ kg, which is consistent with $6.0–6.5 \times 10^8$ kg obtained from field observations.

Weather radars of JMA also captured the volcanic ash cloud from the explosive eruption of Aso on October 8, 2016 (JST). Sato et al. (2018) used five radars' data and found that the ash cloud travel more than 200 km away from the crater. The eruption altitude was estimated to be 12,000 m ASL $\pm$ 687 m (1σ). Using this result and the duration of the earthquake (160–220 s) due to the eruption, the total mass of the ejecta was estimated to be 3.2–7.5×10^8 kg, which is consistent with the value of the field survey.

Modeling

Data assimilation methods were applied to estimate the mass of eruption plume column. Ishii (2018) developed a data assimilation system based on the 4D-Var for estimating the mass of eruptive columns as a function of altitude and ash particle size and applied this method to analyze the October 8, 2016 eruption of Aso volcano. Using both field observation on ash fall and meteorological radar observations for the data assimilation system, emission mass from the eruption plume column (as a function of altitude and particle size) was estimated and subsequent modeling was consistent with observations. The total mass of eruptive column was estimated to be 1.32×10^8 kg.

Abbreviations
4D-var: four-dimensional variational method; ACTIVE: a controlled-source electromagnetic volcano monitoring experiment; AMT: audio-frequency magnetotelluric; CCFs: cross-correlation functions; JMA: Japan Meteorological Agency; JST: Japan standard time (UTC + 9); VLP: very long period; VRP: volcanic radiative power.

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Authors' contributions
TO drafted the manuscript. AK, YM, JF, CC and VA improved the manuscript. All authors read and approved the final manuscript.

Competing interests
The author declares that they have no competing interests.

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Publisher's Note

FRONTIER LETTER **Open Access**

Salt shell fallout during the ash eruption at the Nakadake crater, Aso volcano, Japan: evidence of an underground hydrothermal system surrounding the erupting vent

Hiroshi Shinohara*, Nobuo Geshi, Akihiko Yokoo, Takahiro Ohkura and Akihiko Terada

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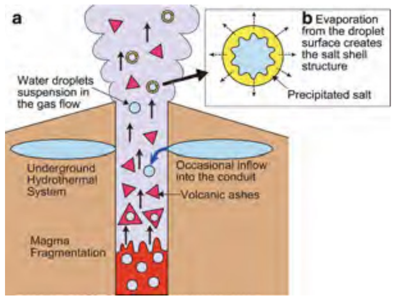
Abstract

A hot and acid crater lake is located in the Nakadake crater, Aso volcano, Japan. The volume of water in the lake decreases with increasing activity, drying out prior to the magmatic eruptions. Salt-rich materials of various shapes were observed, falling from the volcanic plume during the active periods. In May 2011, salt flakes fell from the gas plume emitted from an intense fumarole when the acid crater lake was almost dry. The chemical composition of these salt flakes was similar to those of the salts formed by the drying of the crater lake waters, suggesting that they originated from the crater lake water. The salt flakes are likely formed by the drying up of the crater lake water droplets sprayed into the plume by the fumarolic gas jet. In late 2014, the crater lake dried completely, followed by the magmatic eruptions with continuous ash eruptions and intermittent Strombolian explosions. Spherical hollow salt shells were observed on several occasions during and shortly after the weak ash eruptions. The chemical composition of the salt shells was similar to the salts formed by the drying of the crater lake water. The hollow structure of the shells suggests that they were formed by the heating of hydrothermal solution droplets suspended by a mixed stream of gas and ash in the plume. The salt shells suggest the existence of a hydrothermal system beneath the crater floor, even during the course of magmatic eruptions. Instability of the magmatic–hydrothermal interface can cause phreatomagmatic explosions, which often occur at the end of the eruptive phase of this volcano.

Keywords: Aso volcano, Hydrothermal system, Salt, Fallouts, Ash leachate, Volcanic eruption



Graphical abstract

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FRONTIER LETTER **Open Access**

Temporal variations in discharge rate and component characteristics of tephra-fall deposits during the 2014–2015 eruption of Nakadake first crater, Aso Volcano, Japan

Yasuo Miyabuchi* and Chihoko Hara

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Abstract

The 2014–2015 eruption of the Nakadake first crater at Aso Volcano in southwestern Japan was characterized by continuous ash emissions and intermittent strombolian eruptions. In this paper, we present the distribution, discharged mass, and components of tephra-fall deposits to examine the sequence of activities. We installed 21 ash samplers around the crater (SW crater rim to 9 km in all directions) and calculated the mass of ash-fall deposits based on 28 isomass maps. From November 25, 2014, to the end of January 2015, the cumulative erupted mass increased at a high discharge rate (2.2×10^4 tons/day). After February 2015, the cumulative erupted mass decreased to a low rate of 0.6×10^4 tons/day, although this rate rose slightly in March and late April 2015. The 2014–2015 tephra-fall deposits consisted of glass shards, crystal, and lithic grains. In the November 25–27, 2014 ash-fall deposits, lithic fragments, which are interpreted to be derived from lavas or pyroclasts of previous eruptions, were dominant (59–68%). Thereafter, the proportion of glass shards, which are probably juvenile materials of newly ascending magma, gradually increased with time, and the December 21–23, 2014 ash contained abundant glass grains (63%). The proportions of glass shards ranged from 29 to 50% until February 25, 2015. Subsequently, they decreased with time and reached 14% on March 17. Afterward, the proportions increased again prior to April 27 and ranged between 20 and 30% in May 2015. The total erupted tephra mass from the November 2014–May 2015 activity of Nakadake first crater was 2.1×10^6 tons (1.2×10^4 tons/day), which was less than the tephra deposits of previous activities that have occurred within the past few decades.

Keywords: Erupted mass, Component characteristics, Tephra-fall deposit, Small-scale eruption, Nakadake first crater, Aso Volcano


Graphical abstract

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FULL PAPER **Open Access**

The thermal signature of Aso Volcano during unrest episodes detected from space and ground-based measurements

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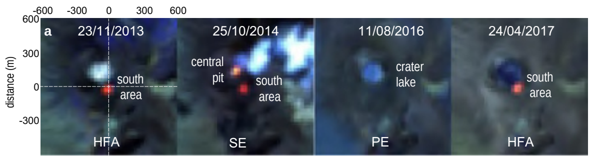
Abstract

The thermal signature of Aso Volcano (Nakadake) during unrest episodes has been analyzed by combining the MODIS-MIROVA data set (2000–2017) with high-resolution images (LANDSAT 8 OLI and Sentinel 2) and ground-based thermal observations (2013–2017). The site of major activity (crater 1) is located at the summit of the volcano and is composed by a fumarole field (located in the South Area) and an acidic lake (replaced by a Central Pit during Strombolian phases). The volcanic radiative power (VRP) obtained by nighttime satellite data during the reference period was mainly below 3 MW. This thermal threshold marks the transition from high fumarole activity (HFA) to Strombolian eruptions (SE). However, periods characterized by sporadic phreatic eruptions (PE, eventually bearing phreatomagmatic episodes), which is the prevalent phase during unrest episodes, exhibit very low VRP values, being around 0.5 MW, or below. The statistical analysis of satellite data shows that the transition from HFA to Strombolian activity (which started on August 2014 and ceased in May 2015) occurs when VRP values are above the cited 3 MW threshold. In particular during marked Strombolian phases (November–December 2014), the radiative power was higher than 4 MW, reaching peak values up to 15.6 MW (on December 7, 2014, i.e., 10 days after the major Strombolian explosion of November 27). Conversely, ground-based measurements show that heat fluxes recorded by FLIR T440 Thermo-camera on the fumarole field of the South Area has been relatively stable around 2 MW until February 2015. Their apparent temperatures were fluctuating around 490–575 °C before the major Strombolian explosive event, whereas those recorded at the active vent, named Central Pit, reached their maxima slightly above 600 °C; then both exhibited a decreasing trend in the following days. During the Strombolian activity, the crater lake dried out and was then replenished by early July, 2016. Then, volcanic activity shifted back to phreatic–phreatomagmatic and the eruptive cycle was completed. During this period, the MIROVA system detected very few thermal alerts and the ground-based measurements were fluctuating around 1 MW. The most violent explosion occurred on October 8, 2016, and within the following weeks measured VRP were moderately above 2 MW. This is coeval with a thermal increase at the fumarole field of the South Area, with temperatures well above 300 °C. Thermal monitoring at Aso Volcano is an additional tool in volcano surveillance that may contribute to near-real-time hazard assessment.

Keywords: Aso Volcano, Unrest episodes, Fumarolic activity, Strombolian activity, Major explosions



Graphical abstract

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FULL PAPER **Open Access**

Temporal variation in source location of continuous tremors before ash–gas emissions in January 2014 at Aso volcano, Japan

Misa Ichimura, Akihiko Yokoo*, Tsuneomi Kagiyama, Shin Yoshikawa and Hiroyuki Inoue

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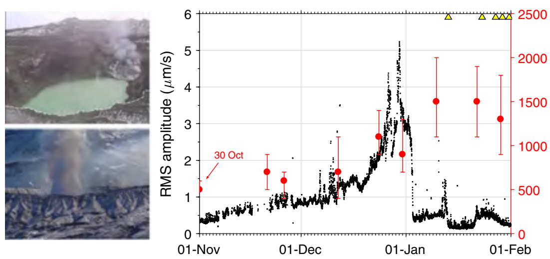
Abstract

Volcanic tremor is often observed to be associated with an increase in volcanic activity and during periods approaching eruptions. It is therefore of crucial importance to study this phenomenon. The opening of a new vent and subsequent ash–gas emissions was observed in the active crater (Nakadake crater) of Aso volcano, Japan, in January 2014. These events were considered to be associated with phreatomagmatic activity similar to the small events of 2003–2005. During the period from December 2013 to January 2014, a significant variation in the amplitude of continuous seismic tremors was observed corresponding to surficial volcanic activity. We estimated the tremor source locations for this two-month period by a three-dimensional grid search using the tremor amplitude ratio of 5–10 Hz band-pass filtered waveforms. The estimated source locations were distributed in a roughly cylindrical region (100–150 m in diameter) ranging from the ground surface to a depth of 400 m. Migration of the estimated source location was also identified and was associated with changes in volcanic activity. We assumed that the source locations coincided with a conduit system of the volcano, consisting of networks of fractures. This area is likely situated above the crack-like conduit proposed in previous studies. Before the 2014 event, an increase in gas-dominated volcanic fluid first caused an enlargement of the conduit zone, followed by the migration of further magmatic fluid through other pathways, which resulted in a subsequent ash–gas emission. Although we do not have sufficient information to discuss the causal relationship between these processes, it seems reasonable that continuous tremors might change the conduit conditions.

Keywords: Aso volcano, Volcanic continuous tremors, Source location, Pathway of volcanic fluids



Graphical abstract

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FULL PAPER **Open Access**

Amphibole–melt disequilibrium in silicic melt of the Aso-4 caldera-forming eruption at Aso Volcano, SW Japan

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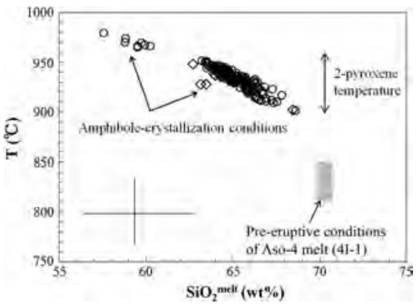
Abstract

The most recent and largest caldera-forming eruption occurred at ~ 90 ka at Aso Volcano, SW Japan, and is known as the "Aso-4 eruption." We performed chemical analyses of amphibole phenocrysts from Aso-4 pyroclasts collected from the initial and largest pyroclastic unit (4I-1) of the eruption to infer the composition–temperature–pressure conditions of the melt that crystallized amphibole phenocrysts. Each amphibole phenocryst is largely chemically homogeneous, but inter-grain chemical variation is observed. Geothermometry, geobarometry, and melt–SiO_2 relationships based on amphibole single-phase compositions reveal that most amphibole phenocrysts were in equilibrium with hydrous melt comprising ~ 63–69 wt% SiO_2 (SiO_2^{melt}) at 910–950 °C, although several grains were crystallized from more mafic and higher-temperature melts (~ 57–60.5 wt% SiO_2 and 965–980 °C). The amphibole temperatures are comparable with those previously estimated from two-pyroxene geothermometry, but are much higher than temperatures previously estimated from Fe–Ti oxide geothermometry. The estimated SiO_2^{melt} contents are lower than that of the host melt in the 4I-1 pyroclasts. Chemical and thermal disequilibrium between the amphibole rims and the host melt, as well as intra-grain homogeneity and inter-grain heterogeneity of amphibole compositions, suggests that these amphiboles were incorporated into the host melt immediately prior to the caldera-forming eruption. Our results suggest that the amphibole phenocrysts, and perhaps some of the pyroxene and plagioclase phenocrysts, were derived from a chemically and thermally zoned crystal mush layer that had accumulated beneath the chamber of the host 4I-I melt. Amphibole geobarometry indicates a crystallization depth of ~ 13.9 ± 3.5 km, which is consistent with the present-day magma chamber depth beneath the volcano as inferred from geophysical observations. The results suggest that the depth of the post-caldera magma plumbing system is strongly influenced by a relic magma reservoir related to a previous caldera-forming eruption.

Keywords: Amphibole, Aso Volcano, Caldera, Crystal mush, Thermobarometry



Graphical abstract

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FULL PAPER **Open Access**

Physical characteristics of scoriae and ash from 2014–2015 eruption of Aso Volcano, Japan

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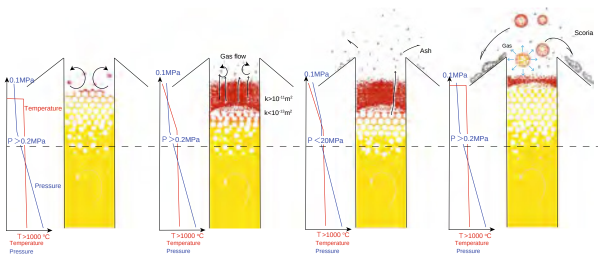
Received: 28 March 2018, Accepted: 21 August 2018, Published: 15 September 2018

Abstract

The activity at Aso Volcano was mainly defined as a sequence of ash emissions and occasional ejections of scoria fragments with ash. Ash emissions sometimes started without notable explosions. The measured porosity of scoriae was as high as 0.94. The scoriae had a flattened shape with a low-porosity outer rim. To elucidate the eruptive conditions causing such ash emission and generation of scoriae, we conducted three series of measurements. First, we heated the high-porosity scoriae from Aso Volcano at 900–1150 °C and found that the heated scoriae shrunk by losing the gas in the bubbles. At the highest temperature, 1150 °C, bubbles segregated from the surrounding melt. Second, we conducted shear deformation experiments of scoriae and ash at 500–950 °C and found that the high-porosity scoriae easily fractured by low normal and shear stresses of ~ 10^4Pa at a low temperature of 500 °C. We also found that the fine ash at a high temperature of 950 °C was sintered. Third, we measured the permeability of the sintered ash plate and unheated powder-like ash layer. The permeability of the ash plate is less than 2.5×10^{-13}m^2, while that for the ash powder is greater than 10^{-11}m^2. The unheated ash particles could move in the container during the permeability measurements. This effect allowed the formation of pipe-like structures in the ash layer and increased its permeability. On the basis of these measurements, we infer the conditions inside the erupting conduit. There exists high-porosity magma foam in the conduit. The top of the magma foam is cold (<500 °C) and has a sufficiently high porosity (>0.7) to be fractured at a low stress level (~ 10^4Pa). The fractured magma foam generates the ash layer above the magma foam. The gas flow from the underlying magma foam makes the high-permeability structure in the ash layer. Eventually, the bottom of the ash layer sinters to regulate the gas flow. The pressurized magma foam breaks the sintered ash layer. The breakage at the bottom of the ash layer may not cause a notable explosion but causes ash emission. The fragmented magma foam becomes high-porosity scoriae at a high temperature, which can generate the low-porosity outer rim by shrinkage and flatted shape.

Keywords: Foam, Rheology, Friction, Fracturing, Permeability



Graphical abstract

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FULL PAPER **Open Access**

Variation of volcanic gas composition during the eruptive period in 2014–2015 at Nakadake crater, Aso volcano, Japan

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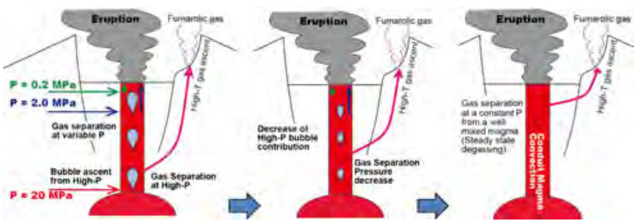
Received: 28 March 2018, Accepted: 5 September 2018, Published: 21 September 2018

Abstract

Volcanic gas composition measurement by Multi-GAS was repeated during the eruptive period in 2014–2015 as well as the quiet period preceding the eruption at Nakadake crater, Aso volcano. The eruptive activity is characterized by continuous ash emission with intermittent Strombolian activity and temporal pauses. Volcanic gas composition measured during the eruptive period showed a rapid and large variation. In particular, the CO_2/SO_2 and SO_2/H_2S ratios varied in the rages of 1–8 and 3–300 during the ash eruption with a clear negative correlation. The large variation and the negative correlation of the compositions are attributed to two orders of magnitude difference of degassing pressure, such as 20 and 0.2 MPa; the gases with the large CO_2/SO_2 and the small SO_2/H_2S ratios are derived from the high pressure. The rapid and large composition variation suggests frequent ascent of bubbles formed at various depth during the eruption. The maximum CO_2/SO_2 ratio decreased with decreasing eruption intensity that suggests decrease in contribution of the bubbles derived from a large depth. With time, H_2O/SO_2 ratio of the gases increases from 30 to >60, suggesting increase in a hydrothermal contribution.

Keywords: Aso volcano, Eruption, Volcanic gas, Multi-GAS, Degassing



Graphical abstract

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FULL PAPER **Open Access**

Shallow volcanic reservoirs and pathways beneath Aso caldera revealed using ambient seismic noise tomography

Yu-Chih Huang*, Takahiro Ohkura, Tsuneomi Kagiyama, Shin Yoshikawa and Hiroyuki Inoue

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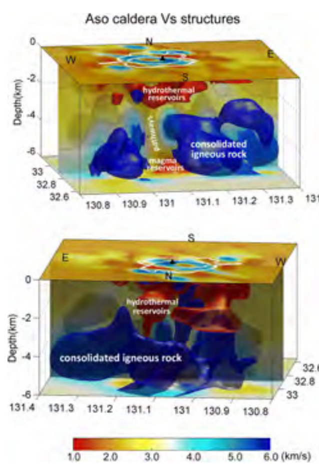
Abstract

Imaging the shallow velocity structures beneath Aso caldera is necessary to further understand volcanism at the volcano and in the region. The network for monitoring Aso volcano has been progressively renewed and upgraded with denser and more modern instruments. We used approximately 4 years of seismic data recorded by a network of 25 seismic stations to image S-wave velocity (*Vs*) structures beneath Aso caldera with seismic noise interferometry. We calculated daily cross-correlation functions (CCFs) of broadband and short-period station pairs separately and then stacked CCFs monthly, to obtain the time-domain empirical Green's functions and corresponding Rayleigh-wave phase-velocity dispersion curves. Finally, we constructed 1–5-s phase-velocity maps interpolated from nodes spaced 0.05° grid. The maps allow investigating crustal *Vs* structures between the surface and a depth of 6 km, likely related to shallow volcanic reservoirs and pathways. High velocities are found within the first kilometer of the crust beneath post-caldera central cones. Low velocities in the center of the post-caldera central cones extend from the surface to a depth of 1–2.5 km; we infer that the anomalies mark shallow hydrothermal reservoirs likely replenished by precipitation and hydrographic networks. The prevalence of high velocities below 3 km can be considered as consolidated igneous rock. Low-velocity anomalies identified at depths of 5–6 km beneath the post-caldera central cones could be a manifestation of magma accumulation. The low-velocity belts situated at 2.5–5 km depths are likely pathways for the transfer of hydrothermal fluids, volcanic gases, or melting magma to the surface. The northern part of the caldera shows relevant lateral velocity variations, with low velocities and high velocities predominant in the east and west, respectively. Other low-*Vs* anomalies appear near the surface to the west and northwest of Aso caldera.

Keywords: Ambient seismic noise, S-wave velocity structure, Aso caldera, Shallow crust, Volcanic reservoirs and pathways



Graphical abstract

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FULL PAPER **Open Access**

Petrological characteristics and volatile content of magma of the 1979, 1989, and 2014 eruptions of Nakadake, Aso volcano, Japan

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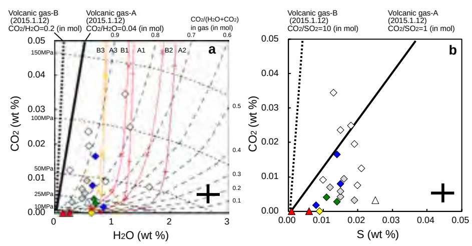
Abstract

Petrological observations and chemical analyses of melt inclusions in scoria were used to investigate the magma ascent and eruption processes of the 1979, 1989, and 2014 eruptions of Nakadake, Aso volcano, Japan. Major elements and sulfur contents of the melt inclusions were determined using an electron probe microanalyzer, and their water and CO_2 contents were determined using secondary ion mass spectrometry. Five scoria specimens from the 2014 eruptions had an andesite composition identical to the scoria from the 1979 and 1989 eruptions. Thermometry using the chemical composition of the groundmass and the rims of the phenocrysts indicated that the temperature of the 2014 magma was 1042–1092 °C. Melt inclusions in plagioclases, clinopyroxenes, and olivines in the 2014 scoria had an andesite composition similar to that of the groundmass. The volatile content of the melt inclusions was 0.6–0.8 wt% H_2O, 0.003–0.017 wt% CO_2, and 0.008–0.036 wt% S. The variation in CO_2 and S content of the melt inclusions was not correlated with the K_2O content, suggesting that the magma degassed as pressure decreased. Melt inclusions in plagioclases, clinopyroxenes, and olivines from the 1979 and 1989 scoria had similar major elements and volatile content to the 2014 eruption specimens. The similarity in chemical composition of both the whole-rock and melt inclusions among all samples suggests that the magmas of these eruptions were derived from the same magma chamber. The gas saturation pressure estimated from the H_2O and CO_2 contents of the 1979, 1989, and 2014 scoria ranged from 18 to 118 MPa, corresponding to depths of 1–4 km. Comparison of this depth with geophysical observations suggests that the inclusion entrapments occurred in the upper part of the magma chamber and/or a conduit. By combining the melt inclusion analysis with volcanic gas observations, we estimated the bulk volatile content of the magma. Based on the bulk sulfur content of the magma and the SO_2 flux between January 2014 and December 2017, the amount of degassed magma over that period was estimated to be the equivalent of 1–3 km^3 of dense rock. The estimated volume was more than 600 times larger than that of products erupted during the same period. This suggests that magma degassing occurred at several depths in the magma chamber due to magma convection in a conduit.

Keywords: Aso volcano, Nakadake, Magma, Eruption, Magma ascent, Degassing, Melt inclusion, Volatile, Magma plumbing system



Graphical abstract

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FULL PAPER **Open Access**

Continuous monitoring of soil CO_2 flux at Aso volcano, Japan: the influence of environmental parameters on diffuse degassing

Masaaki Morita*, Toshiya Mori, Akihiko Yokoo, Takahiro Ohkura and Yuichi Morita

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Abstract

Continuous measurements of soil CO_2 flux are useful for understanding degassing processes and for monitoring volcanic activities. Recent studies at many volcanoes have revealed that soil CO_2 flux variations are significantly influenced by environmental parameters as well as volcanic processes. In this study, we conducted continuous monitoring of soil CO_2 flux in the flank of Nakadake cone, Aso volcano, Japan, from January 2016 to November 2017. The results of our observations during an active period before and after a large phreatomagmatic eruption on 8 October 2016 and during a calm period from 2017 showed variations in soil CO_2 flux due to oscillations in environmental parameters. Excluding these variations from the raw time series by multivariate linear regression analysis, the time series of soil CO_2 flux presented some anomalous peaks in both the active and calm periods. Careful comparison of the anomalous peaks with the environmental parameters revealed that most of the anomalous peaks were likely due to an increase in wind speed and/or a decrease in barometric pressure. However, the anomaly after the 8 October 2016 eruption was not completely explicable by the variations in the environmental parameters and coincided with increases in seismic amplitude and plume SO_2 flux. This anomaly was possibly attributed to an increase in magmatic CO_2 flux. These findings emphasized the importance of careful statistical treatment of the soil CO_2 flux data after excluding the influences of the environmental parameters at each measurement site. These statistical treatments will contribute to a better understanding of the degassing processes and monitoring of volcanic activities, including phreatic or phreatomagmatic eruptions.

Keywords: Aso volcano, Soil CO_2 flux, Accumulation chamber method, Multiple linear regression analysis, Environmental parameters

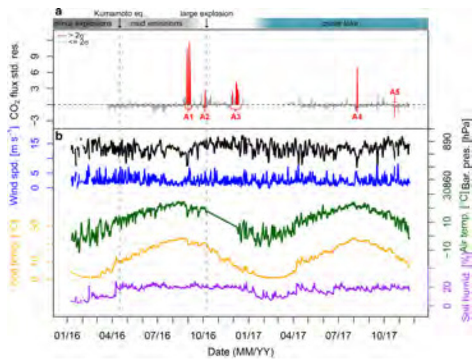

Fig. 9

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FULL PAPER **Open Access**

Monochromatic infrasound waves observed during the 2014–2015 eruption of Aso volcano, Japan

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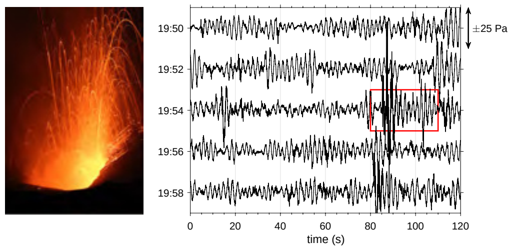
Abstract

Monochromatic infrasound waves are scarcely reported volcanic infrasound signals. These waves have the potential to provide constraints on the conduit geometry of a volcano. However, to further investigate the waves scientifically, such as how the conduit shape modulates the waveforms, we still need to examine many more examples. In this paper, we provide the most detailed descriptions of these monochromatic infrasound waves observed at Aso volcano in Japan. At Aso volcano, a 160-day-long magmatic eruption occurred in 2014–2015 after a 20-year quiescent period. This eruption was the first event that we could monitor well using our infrasound network deployed around the crater. Throughout the entire eruption period, when both ash venting and Strombolian explosions occurred, monochromatic infrasound waves were observed nearly every day. Although the peak frequency of the signals (0.4–0.7 Hz) changed over time, the frequency exhibited no reasonable correlation with the eruption style. The source location of the signals estimated by considering topographic effects and atmospheric conditions was highly stable at the active vent. Based on the findings, we speculate that these signals were related to the resonant frequencies of an open space in the conduit: the uppermost part inside the vent. Based on finite-difference time-domain modeling using 3-D topographic data of the crater during the eruption (March 2015), we calculated the propagation of infrasound waves from the conduit. Assuming that the shape of the conduit was a simple pipe, the peak frequency of the observed waveforms was well reproduced by the calculation. The length of the pipe markedly defined the peak frequency. By replicating the observed waveform, we concluded that the gas exhalation with a gas velocity of 18 m/s occurred at 120 m depth in the conduit. However, further analysis from a different perspective, such as an analysis of the time difference between the arrivals of infrasound and seismic waves, is required to more accurately determine the conduit parameters based on observational data.

Keywords: Monochromatic infrasound wave, Aso volcano in Japan, The 2014–2015 eruption, Air resonance in the conduit



Graphical abstract

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FULL PAPER **Open Access**

Gas flow dynamics in the conduit of Strombolian explosions inferred from seismo-acoustic observations at Aso volcano, Japan

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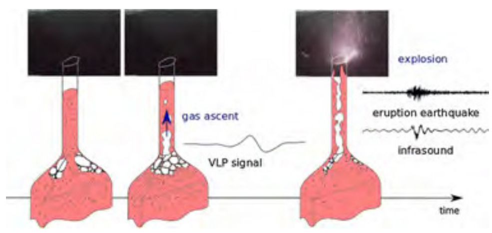
Abstract

Strombolian explosions are one of the most studied eruptive styles and are characterized by intermittent explosions. The mechanism of a Strombolian explosion is modeled as a large gas pocket (slug) migrating through the magma conduit and then bursting at the air–magma interface. These ascending and bursting processes of the slug induce characteristic seismo-acoustic signals during each explosion: very-long-period (VLP) seismic signals, eruption earthquake signals, and infrasound signals. However, at Stromboli volcano, it has been reported that the ascent velocity estimated from the time differences between observed signals is nearly an order of magnitude higher than that expected from laboratory experiments simulating slug ascent. This discrepancy between observation-based and experiment-based velocities has not yet been fully explained and strongly suggests that the conventional model of Strombolian explosions should be partially revised. In this study, we attempted to validate the model of Strombolian explosions by estimating the gas phase velocity in the conduit in the case of Aso volcano. We recorded seismo-acoustic signals accompanying Strombolian events at Aso volcano, Japan, in late April 2015 via our monitoring network, and the ascent velocity of the gas phase was determined from the difference in arrival times between the VLP signals and the infrasound signals. Our estimated velocity exceeded 100 m/s, which is much faster than the experimental value of 7.5 m/s predicted for Aso volcano. To explain this rapid ascent velocity, we propose a revised model describing the migration of the gas phase via a more complicated mechanism, such as annular flow. In this model, we assumed that the gas phase ascends in the conduit at high velocity while making a pathway leading to the magma surface, most likely due to a temporary increase in the gas flux. Our model will help to deepen the understanding of the complicated dynamics in the magma conduit during a Strombolian explosion.

Keywords: Strombolian explosion, Aso volcano, Slug ascent velocity, Seismo-acoustic signals



Graphical abstract

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FULL PAPER **Open Access**

Transport of ballistic projectiles during the 2015 Aso Strombolian eruptions

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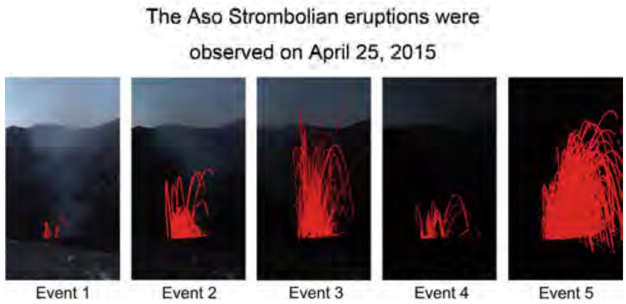
Received: 30 August 2018, Accepted: 15 April 2019, Published: 27 April 2019

Abstract

Large pyroclasts—often called ballistic projectiles—cause many casualties and serious damage on people and infrastructures. One useful measure of avoiding such disasters is to numerically simulate the ballistic trajectories and forecast where large pyroclasts deposit. Numerical models are based on the transport dynamics of these particles. Therefore, in order to accurately forecast the spatial distribution of these particles, large pyroclasts from the 2015 Aso Strombolian eruptions were observed with a video camera. In order to extrapolate the mechanism of particle transport, we have analyzed the frame-by-frame images and obtained particle trajectories. Using the trajectory data, we investigated the features of Strombolian activity such as ejection velocity, explosion energy, and particle release depth. As gas flow around airborne particles can be one of the strongest controlling factors of particle transport, the gas flow velocities were estimated by comparing the simulated and observed trajectories. The range of the ejection velocity of the observed eruptions was 5.1–35.5 m/s, while the gas flow velocity, which is larger than the ejection velocity, reached a maximum of 90 m/s, with mean values of 25–52 m/s for each bursting event. The particle release depth, where pyroclasts start to move separately from the chunk of magmatic fragments, was estimated to be 11–13 m using linear extrapolation of the trajectories. Although these parabolic trajectories provide us with an illusion of particles unaffected by the gas flow, the parameter values show that the particles are transported by the gas flow, which is possibly released from inside the conduit.

Keywords: Ballistics, Gas flow, Image analysis, Acoustic energy, Strombolian eruptions



Graphical abstract

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EXPRESS LETTER **Open Access**

Using Himawari-8, estimation of SO_2 cloud altitude at Aso volcano eruption, on October 8, 2016

Kensuke Ishii*, Yuta Hayashi and Toshiki Shimbori

Earth, Planets and Space 2018, **70**:19 DOI:10.1186/s40623-018-0793-9
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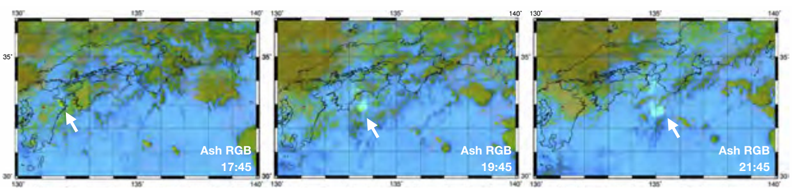
Abstract

It is vital to detect volcanic plumes as soon as possible for volcanic hazard mitigation such as aviation safety and the life of residents. Himawari-8, the Japan Meteorological Agency's (JMA's) geostationary meteorological satellite, has high spatial resolution and sixteen observation bands including the 8.6 μm band to detect sulfur dioxide (SO_2). Therefore, Ash RGB composite images (RED: brightness temperature (BT) difference between 12.4 and 10.4 μm, GREEN: BT difference between 10.4 and 8.6 μm, BLUE: 10.4 μm) discriminate SO_2 clouds and volcanic ash clouds from meteorological clouds. Since the Himawari-8 has also high temporal resolution, the real-time monitoring of ash and SO_2 clouds is of great use. A phreatomagmatic eruption of Aso volcano in Kyushu, Japan, occurred at 01:46 JST on October 8, 2016. For this eruption, the Ash RGB could detect SO_2 cloud from Aso volcano immediately after the eruption and track it even 12 h after. In this case, the Ash RGB images every 2.5 min could clearly detect the SO_2 cloud that conventional images such as infrared and split window could not detect sufficiently. Furthermore, we could estimate the height of the SO_2 cloud by comparing the Ash RGB images and simulations of the JMA Global Atmospheric Transport Model with a variety of height parameters. As a result of comparison, the top and bottom height of the SO_2 cloud emitted from the eruption was estimated as 7 and 13–14 km, respectively. Assuming the plume height was 13–14 km and eruption duration was 160–220 s (as estimated by seismic observation), the total emission mass of volcanic ash from the eruption was estimated as 6.1–11.8 × 10^8 kg, which is relatively consistent with 6.0–6.5 × 10^8 kg from field survey.

Keywords: Ash RGB, Himawari-8, Atmospheric transport model, SO_2, Aso volcano



Graphical abstract

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EXPRESS LETTER | Open Access

Aso volcano eruption on October 8, 2016, observed by weather radars

Eiichi Sato*, Keiichi Fukui and Toshiki Shimbori

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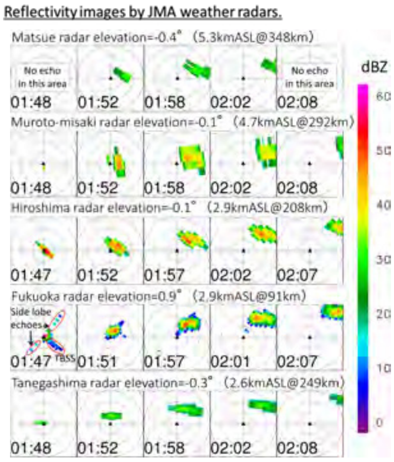
Abstract

An explosive eruption occurred at the Naka-dake first crater of Aso volcano at 1:46 on October 8, 2016 (JST). According to the field survey conducted by Kumamoto University, Kyoto University, the National Institute of Advanced Industrial Science and Technology, and the Japan Meteorological Agency (JMA), a large amount of ash fell in the northeast direction of Mt. Aso; in addition, ash falls were confirmed in Kumamoto, Oita, Ehime Kagawa and Okayama Prefectures. Although the eruption was not observed using a distant camera, the eruption cloud echoes were captured by five JMA operational weather radars (Fukuoka, Hiroshima, Tanegashima, Muroto-misaki and Matsue). Using these radars, we found that the eruption cloud echo moved in the northeast direction at the lower troposphere, and in the east-northeast direction at the middle troposphere. This result is consistent with the vertical wind shear observed by the JMA wind profiler. After that, the echo of the volcanic ash cloud in the middle troposphere flowed more than 200 km from Mt. Aso and became ambiguous near Tosa Bay in Kochi Prefecture. In this study, we introduce a new probabilistic plume height estimation method. This method probabilistically evaluates errors due to radar beam width and refractivity of the atmosphere. Using this method, the eruption cloud height is estimated at 12,000 ± 687 m (1σ) above sea level (ASL). This height is lower than 13–14 km, the SO_2 cloud altitude estimated by Himawari-8 Ash RGB and the JMA Global Atmospheric Transport Model and is also lower than the radar echo height indicated by JMA (15 km). However, the plume height derived using this method is consistent with 39,000 feet (11.9 km) ASL and the volcanic eruption cloud height analyzed by the Tokyo Volcanic Ash Advisory Center using Himawari-8 infrared bands. Based on the result of the probabilistic estimation method and the duration of the volcanic earthquake due to the eruption (160–220 s), the total emission mass was estimated to be 3.2–7.5 × 10^8 kg, which is almost consistent with the field survey (6.0–6.5 × 10^8 kg).

Keywords: Weather radar, Remote sensing, Volcanic plume, Eruption cloud, Aso volcano



Graphical abstract

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EXPRESS LETTER | Open Access

Temporal variation in the resistivity structure of the first Nakadake crater, Aso volcano, Japan, during the magmatic eruptions from November 2014 to May 2015, as inferred by the ACTIVE electromagnetic monitoring system

Takuto Minami*, Mitsuru Utsugi, Hisashi Utada, Tsuneomi Kagiyama and Hiroyuki Inoue

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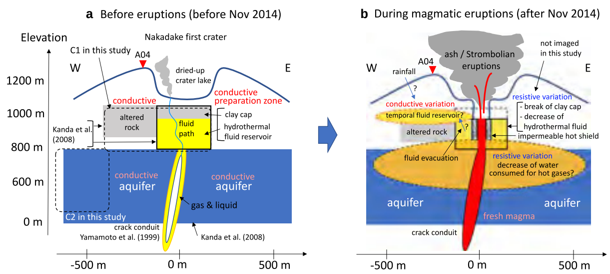
Received: 5 April 2018, Accepted: 11 August 2018, Published: 23 August 2018

Abstract

During the last magmatic eruption period of Aso volcano (November 2014 to May 2015), a controlled-source electromagnetic volcano monitoring experiment (ACTIVE) was conducted. Here, we interpret the temporal variations in the electromagnetic responses. The ACTIVE system installed at the first Nakadake crater, the only active crater of Aso, consisted of a transmitter located northwest of the crater and four (before the eruptions) or three (after the eruptions) vertical induction coil receiver stations. The ACTIVE system succeeded in detecting temporal variations in the resistivity structure during the latest magmatic eruption period. The response amplitude started to increase in November 2014, peaked in February 2015, and decreased slightly in August 2015. An unstructured tetrahedral finite element three-dimensional inversion that accounted for topographic effects was used to interpret temporal variations in the ACTIVE response. The 3-D inversion results revealed that temporal variations in the ACTIVE response are attributed mainly to (1) a broad increase in resistivity at elevations from 750 to 850 m, not only directly beneath the crater bottom but also outside the crater, and (2) a thin layer of decrease in resistivity at the elevation of ~ 1000 m on the western side of the crater. The increase in resistivity can be ascribed to a decrease in the amount of conductive groundwater in the upper part of an aquifer located below the elevation of 800 m, while the decrease in resistivity implies that enhanced fluid temperature and pressure changed the subsurface hydrothermal system and formed a temporal fluid reservoir at the shallow level during the magmatic eruption period.

Keywords: Aso volcano, ACTIVE, Resistivity structure, Magma, Eruption, Monitoring, Controlled source



Graphical abstract

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EXPRESS LETTER Open Access

Estimation of emission mass from an eruption plume for the Aso volcano eruption, on October 8, 2016, using a four-dimensional variational method

Kensuke Ishii

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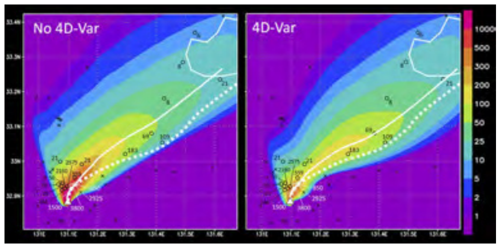
Abstract

When an explosive eruption, such as a Plinian eruption, occurs, in order to estimate ash fall around the volcano and for hazard mitigation, a numerical model is often used. Simulation by a numerical model needs emission mass from the eruption column including vertical profile and size distribution of ash particles. Hence, the accuracy of the emission mass from the eruption column is vital to estimate and forecast ash fall accurately. We developed a data assimilation system based on the four-dimensional variational method (4D-Var) as an estimation method for emission mass from volcanic eruption columns as a function of altitude and ash particle size. This system includes a forward model which calculates volcanic ash forecast, and an observation operator, which are used for the calculation of misfit between observation and forecast. It also includes an adjoint model of the forward model which calculates the correction of emission mass from the misfit, and an algorithm to minimize the cost function as a measurement of optimization. In this system, observation and prior knowledge about emission mass from the volcanic eruption column, such as the Suzuki function, can be simultaneously treated with weight considering observation error and background error. Furthermore, this system has scalability for additional observations. That is to say, a variety of observations can be treated simultaneously, only if their observation operators which are an transformation from model parameters to observation value are developed. In this study, we applied this system to the October 8, 2016 Aso volcano eruption in Japan. After this eruption, ash fall observation (including lapilli) around Aso volcano was preformed, and operational weather radar captured the eruption cloud echo. Using both of these observations and the 4D-Var system, we estimated emission mass from the eruption plume column as a function of altitude and particle size, and it led to ash fall simulation which was consistent with observations. In addition, the eruption mass which is the sum of emission mass from eruption column was estimated to be 1.32×10^{8} kg.

Keywords: Data assimilation, Four-dimensional variational method, 4D-Var, Atmospheric transport model, Aso volcano



Graphical abstract

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EXPRESS LETTER Open Access

Temporal variations of plume activities before the 8 October 2016 eruption of Aso volcano, Japan, detected by ground-based and satellite measurements

Masaaki Morita

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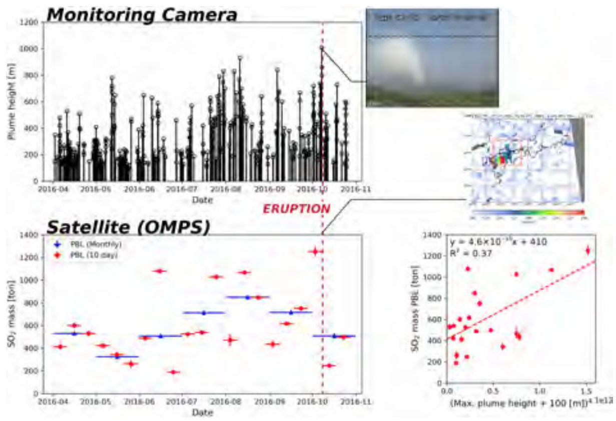
Abstract

At many volcano observatories, measurements of the plume height are frequently applied. On the other hand, the recent development of the satellite measurements enables the monitoring of the SO_2 mass emitted by the passive degassing at sufficient temporal resolution. Using these two techniques, this study focuses on the degassing activity before the 8 October 2016 phreatomagmatic eruption of Aso volcano, Japan. Here we show the temporal variations of the plume height, the SO_2 mass, and ground-based SO_2 flux during 6 months before the eruption. Our result shows similar temporal changes of them, especially for the maxima and the increase, respectively, in about 2 months and 6 days before the eruption. This result indicates that the degassing system had been stable during the whole study period, but the accumulation of volcanic gas in the conduit since August might trigger the phreatomagmatic eruption. These techniques can be sufficient to monitor the degassing activity and to detect its precursory change.

Keywords: Aso volcano, Volcanic eruption, Monitoring camera, Volcanic plume, Plume height, SO_2, OMPS



Graphical abstract

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Earth, Planets and Space

EXPRESS LETTER | Open Access

Hydrothermal system of the active crater of Aso volcano (Japan) inferred from a three-dimensional resistivity structure model

Wataru Kanda*, Mitsuru Utsugi, Shinichi Takakura and Hiroyuki Inoue

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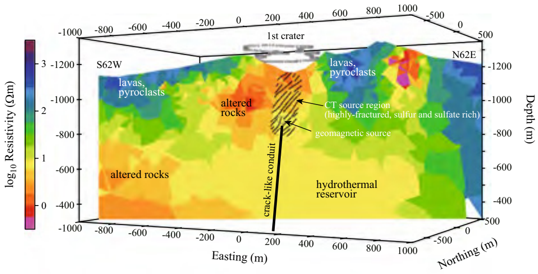
Abstract

During the past two decades, studies of the Aso volcano in Japan have improved our understanding of the shallow hydrothermal system that exists beneath the active crater of this volcano. Detailed knowledge of the subsurface structure of this volcanic edifice is essential for developing a better understanding of the behavior of the volcanic fluids and of the triggering mechanism of volcanic eruptions. Here, we report a three-dimensional (3-D) electrical resistivity model for the active crater of the Nakadake central cone of Aso volcano using audio-frequency magnetotelluric (AMT) data obtained during 2004–2005. The AMT data were collected at 43 sites on a grid (distance between grid points: ~ 300 m) around the crater. However, as yet, only two-dimensional sectional resistivity models have been generated for this survey area. Using 3-D inversion, we obtain a resistivity model that shows similar characteristics to those of the 2-D models. A highly conductive zone is observed beneath the active crater down to a depth of approximately 300 m. Based on the recent findings regarding the shallow hydrothermal system of the volcano, we interpret this conductive zone to have been formed by highly conductive acidic fluids filling a fractured region. This view modifies the past interpretation made on the 2-D models and promotes understanding of fluid behavior beneath the active crater.

Keywords: Resistivity structure, Audio-frequency magnetotellurics, Three-dimensional inversion, Hydrothermal system, Aso volcano



Graphical abstract

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