Analysis of volcanic deformation at Tokachi-dake volcano by using 3-D boundary element method

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Recent geodetic observations at active volcanoes succeeded in detecting small volcanic deformations associated with volcanic activities. These data can be used for quantitatively understanding the magma dynamics before eruptions. In this study, we calculated the volcanic deformation on the basis of 3-D boundary element method to explain the volcanic deformation data at Tokachi-dake volcano detected by SAR observation (Miyagi et al., 2016). Assuming an ellipsoidal shape pressure sources below the Maetokachi, deformation field at Tokachi-dake area, our forward modeling shows that ellipsoidal shape pressure source was locating at 300 m depth with about 3,000 m^3 volume increase could explain the deformation field observed at Tokachi-dake from SAR data. Using the temporal changes of ground deformation such as detected from GNSS data will enable us to constrain the pressure sources, which may give a new constraint on magma process prior to eruption.

Keywords: Tokachi, volcano deformation, BEM

Finding the ruins from lahar deposit induced by the Heian eruption of Towada volcano, northeast Japan

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At least 12 dwelling sites constructed during the Heian era was discovered at Katagai-Ienoshita ruins (Odate city, Akita prefecture) that is located 40 km far from the Towada volcano. These dwelling sites were buried by pyroclastic deposits, suggesting the occurrence of an ancient volcanic disaster. In this study, we describe and report these pyroclastic deposits. The pyroclastic deposits consist at least two layers: lower brownish orange volcanic ash and upper grayish lapilli tuff. The volcanic ash layer is four to seven cm thick and consisting of volcanic glass, pyroxene crystals, quartz crystals, and clasts of pumice, obsidian, and agate. Thickness of the volcanic ash is constant even on slopes such as the roof of the dwelling (up to 34°). The mantle bedding suggests that the layer is typical of ash fall deposits. The facies of the grayish lapilli tuff layer is massive and poorly sorted, consisting of clasts of pumice, mudstone, and alluvium conglomerate. The pumice clasts are 5 mm to 3 cm in diameter. Matrix of the lapilli tuff is composed of fine to medium sized clasts of volcanic glass, obsidian, agate, and quartz crystals. The grayish lapilli tuff is 100 to 150 cm thick. The lapilli tuff is thicker in depressions of the paleosurface, in other words, it ponded in the depressions. The lapilli tuff fills all the dwellings. Basal contact with the underlying volcanic ash layer is planar and shows no evidence of erosion or hiatus. The dwellings are mainly filled with the lapilli tuff and maintain their architectural structures such as roofs, walls, and floors that partly remain original wood without scorches. The lack of burned charcoal on the wood indicates that the lapilli tuff emplaced in low temperature. The general characteristics of the lapilli tuff indicate debris flow deposition. Poor sorting and massive facies are suggestive of rapid deposition of sediments. Lack of significant destruction in the ruins implies that the debris flow flowed in quite gentle manner. The Heian eruption of Towada volcano caused abundant ash falls (To-a and OYU pumice), pyroclastic flow (KPf), and lahar (Atsumiya flood deposits; Hayakawa 1985). The volcanic ash layer and the lapilli tuff layer at the Katagai-Ienoshita ruins can be correlated with To-a and Atsumiya flood deposits, respectively.

Keywords: Lahar, Towada volcano

Applicability evaluation of the drone-mounted thermal infrared camera to geothermal monitoring at Sumikawa site, Akita Prefecture

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To understand the volcanic activity, it is important to monitor of earthquakes, crustal movement, geothermal activity throughout volcanic quiescence. Especially, the monitoring of geothermal activity is useful as a continuous observation, because the occurrence of high-temperature anomaly and change of heat discharge at the surface are closely related to the movement of magma and hydrothermal systems under the volcano, and also the monitoring of geothermal activity is simple, convenient and cost-effective compared with others.

This presentation would introduce a case study of thermal monitoring at the Sumikawa hot spring where a small phreatic explosion occurred in 1997. In particular, we observed the thermal distribution of the surface using a drone-mounted thermal infrared camera on the 18th October, 2015. And a temperature distribution map with high spatial resolution, roughly 5 cm, was generated from the data. This high resolution map would be made it possible for us to acquire the precise information of geothermal anomaly at the relatively small fumarolic area. Therefor, this method could complement the conventional observing approach of geothermal activity by performing repeatedly with proper timing.

Keywords: drone, geothermal monitoring, temperature distribution map, Sumikawa site

Activization of Zao volcano within the past 100 years and the present activity

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In the recent 100 years major activities occurred on Zao volcano in 1918, 1939, 1966 and continued several years. After the 2011 Tohoku Earthquake increase in seismic activity was reported on 21 active volcanoes in Japan (JMA, 2014). While Zao volcano was out of them, volcanic tremor was observed for the first time in Jan. 2013, and a tremor and preceding tilting occurred in April (JMA, 2013). In addition, partial turbidity was found on Okama crater lake in Oct. 2014. We have started temperature monitoring of fumaroles and springs on Maruyama-sawa geothermal area (hereafter indicated as Maruyama-sawa), 1.5 km NE of Okama in 2012, temperature monitoring and chemical analysis of Okama and Maruyama-sawa water in 2013. We also have watched the confluence of Nigori-kawa and Firiko-zawa (Niizeki-onsen), 1.6 km east of Okama, where hot dense springs appeared in the past activity. Here we review the last three major activities focusing on Okama, Maruyama-sawa and Niizeki-onsen to compare with the present activity.

In 1918 Okama changed its color and then gas emitted from bottom (Omori, 1918), which lasted until 1928. The depth in 1928 was 61 m (Anzai, 1961). Some change accompanied an earthquake at Maruyama-sawa on 12 Aug. 1918 (Imada et al., 1985), although the detail is unclear. Tori-jigoku, killing animals by dense volcanic gas, had formed by 1935 (Anzai, 1961). Niizeki-onsen, developed by tunneling between 1907 and 1908 (sanitation department of Miyagi prefecture, 1969), lowered its temperature in 1917 winter and decreased the discharge by 1/3 in Jun. 1918. Although the temperature recovered temporarily, it was closed due to dry up in 1921.

In 1939 Okama changed its color on the end of July, followed by gas emission and temperature rise. Temperature in the bottom mud was >250 °C in Aug. 1940 (Anzai, 1941). The last turbidity was on Sep. 1942. Maruyama-sawa had weak fumarole activity in Jul. 1939 (Toraishi and Tominaga, 1940), but small explosion occurred on 10 Feb. (Toraishi and Tominaga, 1940) or 16 Apr. (Anzai, 1941), 1940. Niizeki-onsen recovered effusion 18 m away from the old vent in Jun. 1939, and new hot spring appeared 500 m upstream along Nigori-kawa (Ueno, 1940). Temperature was 88 °C on Feb. 1940 (Toraishi and Tominaga, 1940) and ph was 0.3 on May 1940 (Anzai, 1941). A 2 m wide and over 100 °C solfatara was found on the northern slope of the riverside.

No anomaly occurred on Okama in 1966 activity: no gas emission, unchanged depth (27 m line) between 1955 and 1968 (Shida et al., 1969) and monotonous decrease in Ca^{2+} and SO_4^{2-} concentrations between 1955 and 1983 (Shida et al., 1969; Sato and Kato, 1985). In contrast Maruyama-sawa activated its fumarole. At Niizeki-onsen steaming ground appeared on the slope and highly acidic hot spring effused along Nigori-kawa, whose temperature, ph, electrical conductivity (EC) were 77 °C, 0.3, >5 S/m on Oct. 1967 (Shida, 1968).

Based on our observation the present activity seems to be similar to that from 1966 so far. Except $^{129}I/^{127}I$ ratio that may relate to seismic activity (Matsunaka et al., 2014), no obvious change has been observed on Okama; the depth is around 25 m, and Ca^{2+} is 60~70 mg/kg which is almost equal to or slightly lower than that in 1983. Temperature of Maruyama-sawa fumarole is almost constant, but the fumarolic steam has become prominent gradually, especially since autumn of 2014. In addition a trace of mud effusion was found in Oct. 2015. We confirmed in Sep. 2015 that Niizeki-onsen has reactivated upwelling. Temperature, ph and EC on 3 Sep. and 28 Oct. were 32.1 °C and 34.1 °C, 2.3

and 2.0, 0.126 S/m and 0.789 S/m.
Imada et al. (1985) pointed out the center of the activity had moved from Okama to Maruyama-sawa. Except Okama the present activity also resembles that from 1939. We should continue the survey with having the 1940 Maruyama-sawa small explosion in mind.

Keywords: Zao volcano, 2011 Tohoku Earthquake, activization

Temporal change of a hydrothermal system beneath Azuma volcano inferred from the Analysis of N-type events

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1. Introduction
Understanding a hydrothermal system beneath volcano is a key to predict volcanic activities because surface volcanic phenomena are strongly controlled by the physical state of subsurface hydrothermal system. For that purpose, the analysis of N-type events, which are considered to be a resonance of underground fractures, may be a suitable way to estimate the physical properties of fluids inside the fractures (e.g., Kumagai and Chouet, 2000). At Mt. Azuma, N-type events are frequently observed around the time of appearance of a new fumarole on November 11, 2008, and these events have also been observed in recent years. In this study, we analyzed spectral characteristics of N-type events to infer the temporal evolution of hydrothermal system beneath Mt Azuma.
2. Data and Methods
We used vertical-component waveform data recorded at permanent stations TU.AZM (Tohoku Univ.) and V.AZJD (JMA), and apply the Sompi method (e.g., Kumazawa et al, 1990) to estimate four parameters (frequency, damping factor, initial amplitude, initial phase) characterizing each observed waveform. In this study, we mainly examine the time variation of frequencies, quality factors, and spectrum ratios of dominant namiso (wave elements) estimated by the Sompi method to interpret temporal variation of physical parameters of volcanic fluids.
3. Result and Discussions
The temporal variations of oscillatory characteristics of N-type events during two representative time periods from August, 2008 to November, 2008 (Period I) and from October, 2009 to December 2009 (Period II) are summarized as follows: During Period I, dominant frequency gradually shift from 4.0 Hz to 3.0 Hz, while the corresponding Q factors are almost constant. The spectrum ratios between lower mode and higher modes becomes larger as time passes. During Period II, dominant frequency becomes lower in the former part of the period, and settles down to 1.0 Hz. Quality factors and spectrum ratios during this period is almost constant.
These temporal variations of oscillatory characteristics of N-type events are interpreted in terms of temporal evolution of hydrothermal system as follows: During the Period I, the density ratio between fluid inside fractures and surrounding rock becomes larger while the velocity ratio is almost unchanged. This implies that the fluid inside fractures is a mixture of liquid and gas components, and the fraction of gas component becomes smaller during this period. During the Period II, the physical properties of fluid are at stable conditions and it implies steady supply of fluids into the crack.
The fact that the frequencies of most dominant mode in the period I is around 3 Hz while that of the period II is around 1 Hz also indicates that the gas fraction in the hydrothermal fluid during the Period I is larger than that of the Period II, and suggests a long-term variation of hydrothermal system.

Keywords: Azuma, fracture, hydrothermal system, N-type events

Resistivity structure beneath the fumarolic area of Nasu-Chausu-dake inferred from the DC resistivity survey

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Chausu-dake is an active stratovolcano located in the mid-southern part of the Nasu volcanic group. Its volcanic activity started about 16000 years ago, and six large-scale eruptive activities including the magma ejection and many phreatic explosions were reported. The last one was activity during 1408-1410, and a lava dome was formed in the summit area. Phreatic explosions on July 1st, 1881 formed two craters on the northwestern side and western side of the lava dome. Recently, phreatic explosions occurred in these craters in 1953, 1960, and 1963, and fumarolic fields are formed today.
In this study, we carried out the DC resistivity survey in two fumarolic zones and revealed the detailed subsurface resistivity structure. Of the two resistivity survey lines, we referred to the line crossing the northwestern crater as "line A" (total length: 380m, electrode spacing: 10m) and the other line crossing the western crater as "line B" (total length: 300m, electrode spacing: 10m). Measurements were performed for each line by using the Wenner electrode array and Eltran electrode array which have different sensitivity to subsurface structure each other. The observed data were converted to the apparent resistivity distribution with different electrode spacing, and the 2D resistivity model was inferred using a 2D inversion program based on Sasaki (1981) which solves the non-linear least squares method using finite element meshes. The resistivity structure models obtained by this way were compared with the geological map of Nasu volcano presented by Yamamoto and Ban (1997), and with the resistivity model that was estimated from the AMT data of Aizawa et al.(2009).
As the result, we interpreted high resistivity zones near the surface as the andesitic lava and/or pyroclastic rocks which erupted about 100 thousand years ago, and low resistivity zones corresponded to a hydrothermal fluid and/or the hydrothermally altered zone because the fumarolic gases and the altered rocks were seen at the surface. The resistivity structure model of the line B showed that the low resistivity zone extends to the south of the crater, which is consistent with the 1D model of Aizawa et al.(2009).
In this study, we could interpret only the shallow resistivity structure because the obtained data was of low quality to infer a deep structure. To constrain a deeper and wider subsurface structure and to identify the presence of hydrothermal fluid, we are planning to carry out the AMT survey over the whole area of lava dome.

Keywords: Nasu volcano, fumarolic zone, DC resistivity survey, resistivity structure

Resistivity structure of Kusatsu-Shirane volcano inferred from a magnetotelluric survey

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Kusatsu-Shirane volcano is an active volcano located in the northeastern part of Gunma prefecture. There are some craters on the summit area, one of which is the Yugama crater where lake water shows strongly acidic nature. High seismicity is frequently observed beneath the crater. Several hot springs located in the foot of the volcano discharge abundant hot spring water. For these rasons, there seems to be a highly developed hydrothermal system beneath the volcano.
According to the geochemical studies, fumaroles in the summit area, lake water in the Yugama crater and hot springs in the flank are derived from a two-phase hydrothermal fluid reservoir located beneath the Yugama crater. In contrast, hot springs located in the foot of Mt. Moto-Shirane discharge more primary fluids which are mixtures of high temperature volcanic gases and meteoric water (Ohba et al., 2000). In addition, audio-frequency magnetotelluric (AMT) surveys conducted along an E-W profile of the volcano found a 300m-1000m thick conductive layer beneath the eastern slope. This conductor was interpreted as the smectite-rich layer of Pliocene volcanic rocks that plays a role of low-permeable cap separating the fluid path to the hot spring of the eastern slope and the path to the hot spring of the foot of the volcano (Nurhasan et al., 2006). Another AMT survey conducted around the Bandaiko hot spring revealed the existence of a conductor extending to a deeper part beneath the hot spring (Kanda et al., 2014).
These studies revealed the generating process of various kinds of hot spring water and the shallow structure in the area to some extent. However, a deep structure of the volcano has not been understood yet. We conducted a wideband magnetotelluric (MT) survey across Mt. Moto-Shirane to reveal the pathway of hydrothermal fluid from the deeper part, and the location of heat source, that is, the magma reservoir of the volcano.
The survey was carried out at 12 sites along a 10km long E-W profile from the Manza hot spring area via the summit area of Mt. Moto-Shirane to the Bandaiko hot spring. We inverted the observed data by using the code developed by Ogawa and Uchida (1996) to obtain a 2-D resistivity section. Impedance phase and apparent resistivity were used for the inversion, in which the data showing 3-D features were eliminated in advance.
Obtained resistivity structure was characterized by the following features.
(1) Conductive body extending from the summit area to the deeper part of the western flank
(2) Conductive layer at the shallow part of the eastern flank
(3) Large resistive block at the deeper part of the eastern flank
The conductive layer (2) may correspond to the Pliocene volcanic rocks which were found by the previous AMT survey. Beneath this conductive layer, a resistive block (3) lies. Because the observed data was affected by the artificial electromagnetic signals, we need to examine the data carefully to confirm whether the model is true or not. We will give a presentation on the some results of analysis in a poster session.

Keywords: Resistivity structure, Magnetotellurics, Kusatsu-Shirane Volcano

Precise hypocenters in active hydrothermal systems determined by the double-difference technique: Implications for fluid flows at during an inflation event at Kusatsu-Shirane Volcano in 2014

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Earthquake swarms occurred beneath the Shirane pyroclastic cone at Kusatsu-Shirane Volcano in 2014. The seismic activity was followed by an inflation at shallow depth beneath the cone and changes in geomagnetic field and chemical compositions of volcanic gas emitted around the cone. These unusual activities are likely caused by accumulation of hydrothermal fluid at shallow depth beneath the cone. MT surveys revealed that a low permeable layer probably composed of Smectite exist at shallow depth beneath the cone (Ogawa et al., personal communication). Such a subsurface structure may play an important roles in fluid storage and triggering of phereatic eruptions. To understand a relation between subsurface structure and fluid flow, precisely determined hypocenters give valuable clues (Yukutake et al., 2011). Applying the double-difference technique (Waldhauser and Ellsworth, 2000), we precisely relocated hypocenters which occurred in 2013-2014.
To obtain initial locations of hypocenters for applying the Double-Difference technique, reliable seismic velocity structure is necessary. However, it is not well known beneath the cone. Kuwahara et al. (2015) developed a simple 1-D model composed of two layer. Minimized average residuals of P-wave travel times suggest that optimal seismic velocities of upper and lower layer are 2.5 km/s and 4.8 km/s, respectively, which correspond to figures estimated by controlled source seismic experiments (Onizawa et al., 2005; Takeda et al., 2004). A height of bottom of upper layer is estimated to 1,500 m a.s.l. that corresponds to the height of the bottom of low permeable layer, suggesting the upper layer is mainly composed of volcanic rock altered by hydrothermal activities. On the basis of the velocity model mentioned above, we obtained the initial hypocenters of 251 events. For the analysis, we selected events which the P- and S-wave arrival times obtained at six and at least three stations respectively, including three bore-hole type. The cross-correlation measurement consisted of 86,089 P-wave and 37,413 S-wave.
Relocated hypocenters concentrate on the height of 950-1,000 m a.s.l. beneath the center of Yugama crater lake. In March 2014, at the beginning of earthquake swarms periods, relocated hypocenters are same as events in 2013. One of notable feature is that earthquakes began to occur at shallower depth of 1,100-1,300 m a.s.l. from the end of April 2014. In May 2014, an increase in water temperature of Yugama crater lake were observed. Subsurface inflation monitored by tilt meters suggests a fluid storage rate was highest in May 2014. We believe that hydrothermal fluid supplied from depth began to accumulate under the low permeable layer in March 2014. The fluid began to fracture the low permeable layer, and penetrate into shallower part at the end of April. Finally, the fluid began to eject mildly from the lake bottom from May 2014.
Acknowledgement: We are grateful to Dr. Shin’ya Onizawa, Dr. Tomoki Tsutsui and Mr. Rintaro Miyamachi for the field work.

Keywords: Kusatsu-Shirane Volcano, microearthquakes, double-difference method

Volcanic activity of Asama volcano in 2015

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After the end of April, 2015, volcanic earthquakes occurred near Asama volcano have been increased and in June the emission of sulfur dioxide have been increased rapidly. In recognition of the increase in volcanic activity, JMA issued a Near-crater Warning on 11 June and raised the Volcanic Alert Level from 1 to 2. Thereafter, small eruption occurred on 16 and 19 June. In our poster, we report the activity of Asama volcano in 2015 including the activity before and after eruption.
Volcanic seismicity became relatively high from the end of April 2015 at Asama volcano. It became the highest in June, and decreased gradually. Amounts of sulfur dioxide emission had increased in June and decreased gradually. Therefore, there would be some correlation between seismic activity and amounts of sulfur dioxide. The glow was observed after 16 June. The thermal activity has remained at high levels.
The volcanic deformation observed by tiltmeters and EDM (Electronic Distance Measurements) after June 2015, by GNSS observation after May 2015. The expansive deformation was confirmed from the data of tiltmeters. We used the model of a point pressure source and tried to estimate the pressure source of this deformation. For data analysis, we use a software package “MaGCAP-V” (MRI, 2008). The best fit model is a point pressure source located in the west of Asama volcano. The deformation detected by GNSS measurements suggests that there is the source which is deeper than the source inferred by the data of tiltmeters because the movement of GNSS has preceded the movement of tiltmeters.
In our poster, we discuss these results in detail and compare with the past activity.
Acknowledgements: We used the data observed by GSI and NIED. We also used a software package "MaGCAP-V" (MRI, 2008). We would like to express my gratitude to them.

Keywords: Asama volcano, eruption, volcanic deformation

Temporal change of SO_2 discharge at Asama volcano

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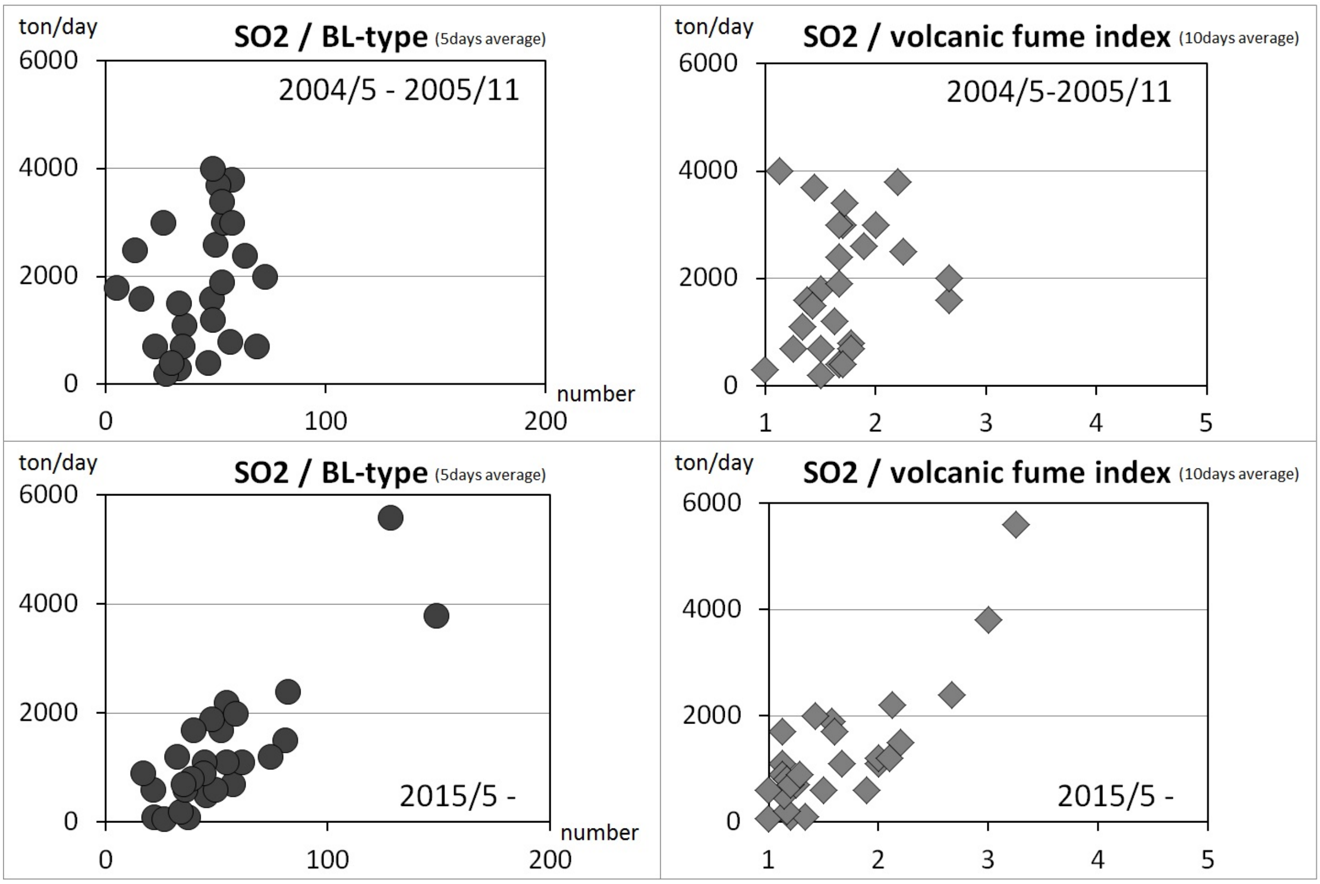
Japan Meteorological Agency (JMA) has been observed amount of SO_2 emission at Asama volcano since July 2002, for the purpose of monitoring the volcanic activity. Based on the observed SO_2 discharge data, we investigate correlations among daily amount of SO_2 emission, volcanic fume index, and frequency of volcanic earthquakes dividing the term into eruption (June 2002 - April 2004, May 2004 - November 2005, August 2008 - July 2009, and May 2015 -) and non-eruption periods.
A positive correlation between frequency of BL-type volcanic earthquake and SO_2 discharge is confirmed during the 2015 eruption period; that between volcanic fume index and SO_2 discharge is in a similar way. The similar correlations are recognized during the eruption periods in 2008 and 2009. On the other hand, we can’t make certain of correlations between frequencies of BL-type event and volcanic fume indexes during the eruption periods in 2003 and 2004; we frequently observed increments of SO_2 emission without increase of BL-type earthquakes and volcanic fumes. (fig.1) A very long-period pulse, hereafter we call it VLP, is an impulsive motion with a dominant period longer than 5 seconds accompanied by a tilt change, which is excited by a sudden gas emission (Maeda and Takeo, 2012). Weak correlations are confirmed between the frequencies of VLP and BL-type event, and between the frequency of VLP and SO_2 discharge. However, there are several examples of large amount of SO_2 emission with a few occurrence of VLP. During non-eruption periods, the daily SO_2 discharge rate could not exceed 2000 ton/day even though the increment of BL-type activity.
The increment of SO_2 emission seems to be plausible data indicating a volcanic eruption potential, and the positive correlations among SO_2 emission, volcanic fume, and daily frequency of volcanic event are confirmed during the 2008, 2009, and 2015 eruption periods. However, there are some observations that SO_2 emission represented weak correlations with the frequencies of BL-type event and with the volcanic fume indexes even though the eruption periods (2003 and 2004). The gas emission system seems to fluctuate along the volcanic activity.

Keywords: Asama volcano, SO2, seismic waveform, volcanic fume


ton/day
SO2 / BL-type (5days average)
2004/5 - 2005/11
number
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SO2 / volcanic fume index (10days average)
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SO2 / BL-type (5days average)
2015/5 -
number
ton/day
SO2 / volcanic fume index (10days average)
2015/5 -

Measurements of soil CO_2 flux at Asama volcano, Japan before and after minor eruptions in June 2015

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Volcanic degassing is not only from plumes or fumaroles in craters but also from soil emanations on volcano flanks. In this soil degassing, carbon dioxide (CO_2) is an important species because of its high abundance in magmatic volatiles and its low solubility in magma. Many previous studies have reported on variations of soil CO_2 flux and its spatial distribution corresponding to changes of volcanic activity [e.g., Hernández *et al.*, 2001, *Science*; Carapezza *et al.*, 2004, *Geophys. Res. Lett.*; Pérez *et al.*, 2006, *Pure Appl. Geophys.*]. Therefore, it is important to monitoring soil CO_2 flux for understanding relations of volcanic degassing and volcanic activity changes.

At Asama volcano, Japan, minor eruptions occurred on 16th and 19th June 2015 that were the first eruptions since 2009. After these eruptions, a measurement of soil CO_2 flux was conducted on 29th October 2015. Here we compare the data of 2015 to those of inactive period in 2012-2014 [Morita *et al.*, *Bull. Volcanol.*, *accepted*] and discuss on fluid ascent before and after the 2015 eruptions.

Soil CO_2 flux was measured using an accumulation chamber method [Parkinson, 1981, *J. Appl. Ecol.*; Baubron et al., 1990, *Nature*; Chiodini et al., 1998, *Appl. Geochem.*] at 54 sampling points in the eastern side of Kamayama flank and Maekake crater rim. A spatial distribution of measured flux was obtained from an average of 100 realizations by sequential Gaussian simulation [Deutsch and Journel, 1998; Cardellini *et al.*, 2003, *J. Geophys. Res.*].

As a result, a spatial distribution of high soil CO_2 flux anomalies in eastern Kamayama flank and eastern Maekake crater rim is similar to that for the 2012-2014 observations reported in Morita *et al.* [*Bull. Volcanol.*, *accepted*]. Comparing the flux values of the 2015 and the 2012-2014 measurements, an average flux of the 100 realizations was about 5-10 times higher in eastern Maekake crater rim and was not changed or a little lower around Kamayama crater rim. Morita *et al.* [*Bull. Volcanol.*, *accepted*] reported that soil CO_2 emitted from the eastern side of the summit probably ascend from a hydrothermal fluid layer corresponding to a low electrical resistive body that resides in the shallow part of the volcano flank [Aizawa *et al.*, 2008, *J. Volcanol. Geotherm. Res.*]. The increase of soil CO_2 flux in eastern Maekake crater rim likely reflect an increasing supply of magmatic volatiles to the hydrothermal fluid layer from the depth. Different responses of soil CO_2 flux between Kamayama and Maekake crater rims may correspond to differences of fluid pathway and ascent process. To ascertain relations between soil CO_2 flux variations and the fluid ascent process from the depth, further repeated observations of soil CO_2 flux and detailed comparisons to the volcanic activity are necessary.

Keywords: Asama volcano, Soil CO_2 flux, Fluid ascent

A permeability evolution model for the 2014 eruption of Mt. Ontake inferred from tilt waveform analyses

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During 450 s before the onset of Mt. Ontake 2014 eruption, very long period (VLP) seismic events and a summit-uplift tilt change were observed. Our waveform inversion solution of the largest VLP event, that took place 25 s before the eruption onset, was an NNW-SSE striking tensile crack at a 600 m depth beneath the eruptive vent region; this result was interpreted as an opening and a closing of one of the preexisting seismic faults caused by ascent of water vapor (Maeda et al., 2015, EPS). Our waveform inversion of the tilt change pointed to a semi-vertical tensile crack at 1 km depth that inflated by 10^6 m^3. The tilt waveform is well explained by a linear function of time during the first 168 s, then switched to an exponential growth at a time constant of 84 s (Maeda et al., 2015 VSJ fall meeting). Interpretations of these results were kept unsolved at that time.

In this presentation, we show our latest model of the tilt change developed after the 2015 VSJ fall meeting. We assume that the inflation of the crack was caused by boiling of underground water at a constant depth (pressure: 20 MPa; depth: ~1 km).

The linear function of time is explained by boiling of underground water under a constant heat supply from depth. Using the volume change rate estimated from the waveform inversion, the heat supply rate is estimated to be 10^{10} J/s, consistent with the surface heat emission estimated after the 2014 eruption (Terada et al., 2014 VSJ fall meeting).

To realize the exponential function, a positive feedback process is needed such that a larger amount of water vapor in the crack leads to more rapid boiling of underground water. As long as a single large crack (10^6 m^3) filled with water vapor is considered, a slow growth lasting for up to 450 s is difficult to realize according to the force balance of Lister and Kerr (1991, JGR). We then regard the tilt source to be a region of many small subparallel cracks filled with water vapor, and model this system as a vertical permeable flow driven by the buoyancy of water vapor. The Darcy velocity equation suggests that the permeability is the only quantity that could significantly vary with time. We therefore consider the following positive feedback: the larger the water vapor in the source volume, the larger the porosity, permeability, and Darcy velocity, leading to faster water vapor migration upward from the boiling depth, which is compensated by increasingly rapid boiling of underground water. We quantified this idea and obtained an exponential growth of the water vapor volume under a proportional relation between the porosity and permeability. The observed time constant of 84 s is explained by a realistic permeability in this model.

In summary, the source process before the Mt. Ontake eruption is modeled by initial boiling of underground water under a constant heating, followed by exponential acceleration of the boiling rate caused by increased porosity and permeability, VLP events caused by ascent of the water vapor, and finally the eruption.

Keywords: Mt. Ontake, Phreatic eruption, Tilt

The rainfall correction of E-W component of the tiltmeter at Mt. Ontake Tanohara (2)

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Most of active volcanoes of Japan are snowcapped during winter. And most of tiltmeters for volcano monitoring are influenced by meltwater.
Kimura and Nakahashi(2015) tried rainfall correction of E-W component of the tiltmeter at Mt. Ontake Tanohara by using the precipitation only, and were able to get the good result for the period when rainfall is liquid (from June to October). As a result, they were able to confirm a tilt change of the mountain rise from around September 10, 2014 in the same timing that earthquakes increased under the summit of Mt. Ontake. However, they cannot correct the influence of meltwater from March to May every year. The meltwater data are necessary to correct influence of meltwater. Kawashima et al.(2015) observed the snow and meteorological data at Mt. Ontake Tanohara, and calculated the amount of meltwater from November, 2014 through May, 2015. Kimura et al.(2015) tried the rainfall correction of E-W component of the tiltmeter at Mt. Ontake Tanohara by using the precipitation and the amount of meltwater, and were able to correct the influence of meltwater of 2015.
The snow and meteorological observation at Mt. Ontake Tanohara was started November, 2015 again. As of January, 2016, there is very less snow than last year, we show the result of the rainfall correction of the tiltmeter at Mt. Ontake Tanohara by using the precipitation and the amount of meltwater of 2016.

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Keywords: tiltmeter, Mt. Ontake, rainfall correction, meltwater

Identification and emplacement mechanisms of the September 2014 eruptive products from Ontake volcano, Japan, inferred from magnetic petrology

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Phreatic eruption occurred at Ontake volcano on the 27th Sept. 2014, have produced wide variety of deposits around the volcano. The eruption column reached to about ten thousand meters high and resulted in thin ash fall deposits extended 100km to the east. Small pyroclastic flow deposits were emplaced at southern slope of the volcano edifice. Though steam emission without additional volcanic products have been observed after the initial intensive activity, heavy rain falls triggered a lahar which transported volcanic materials deposited at around the craters to the foot of the volcano. This study focuses on eruption processes and transport and emplacement mechanisms of the eruptive products. Preliminary results were reported in 2015 JpGU meeting. This time, we will report magnetic petrological features of the eruptive products of Ontake 2014 and discuss emplacement mechanisms of the materials.
Magnetic minerals in the eruptive products are characterized by abundant pyrite and small amount of titanomagnetites. Thermomagnetic analysis indicated that pyrite is stable under 380°C and changes to magnetite above 380°C, suggesting the eruptive materials did not suffer high temperature of more than 380°C just before and during the eruption. Magnetic hysteresis parameters of the materials ejected at the initial stage of the eruption were relatively concentrated around the bottom right corner of the total distribution at Day plot, whereas the other materials were scattered at the upper left. It is suggested that the materials by the initial stage of the eruption contain larger magnetic minerals. On the other hand, field observation and granulometric analysis of the deposits including magnetic minerals indicated that the materials derived from the initial stage are composed of well-sorted fine ash, inconsistent with magnetic hysteresis results. There is a possibility that heavy magnetic minerals bearing iron tend to fall rapidly, resulted in higher concentration of larger magnetic minerals in the materials ejected at the initial stage.
These rock magnetic characters can be used as a marker of the eruptive products. Thin fine ash layer found at the upstream of the Nigori-kawa River, about 3 km south from the vent area, showed similar rock magnetic features with those of the materials caused by the initial stage, whereas such deposits cannot be traced further downstream from the point. The deposit could be derived from ash cloud of pyroclastic flow or from ash fall itself by the initial stage. Approximately 2m thick lahar deposits containing sediments derived from the 2014 eruptions were found along the river, suggesting emplacement of the pyroclastic flow impacted upstream areas of the catchment. Turbidity of the river decreased significantly after a year of the eruption, but a certain amount of the 2014 materials were contained in the river water. This is suggestive of perennial transportation of volcanic materials sourced from the vent area even in the present time.

Keywords: Ontake, phreatic eruption, magetic mineral, pyrite

Study on crack size in anisotropic media in Hakone volcano

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We have studied properties of anisotropic media in Hakone volcano, such as depth dependence of anisotropic intensity and/or its time variations. In this study, we consider the characteristic size of the crack system in the anisotropic media in Hakone volcano. To do so, we examined the confidence band in the frequency domain of the parameters obtained in the S-wave splitting analysis based on the method proposed by Mizuno et al (2001).
Mizuno et al (2001) proposed a quantitative manner to estimate errors in phase differences between two quasi-S waves obtained by a splitting analysis. The phase differences should be constant (confidence band) under the assumption that a considered wavelength is much longer than the size of the cracks. As a frequency becomes higher, the phase differences become frequency-dependent. Therefore, we can estimate the lower limit of the wavelength, that is, the upper limit of crack size from a confidence band of phase differences.
We estimated the upper limit of crack size as 200 ~ 300m in the assumed velocity structure. However, lower limits of wavelength obtained for some observation sites (e.g., KIN and OWD) are longer than those for the other sites. Yukutake et al (2013) reported that there is a low b-value zone beneath the fumarolic area (Owakudani). The low b-value zone is expected to include relatively large cracks. The spacial variations of estimated crack size may be caused by rays passing through the low b-value zone.

Keywords: anisotropy, S-wave splitting, Hakone volcano

Magnetic variation of total intensity associated with volcanic activity observed around Owakudani, Hakone Volcano

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Volcanic event of Hakone in 2015 began in late March by slight extension of baseline length observed by GNSS network, and in late April the volcanic seismicity increased including many felt earthquakes as well as fumarole of Owakudani became more active. InSAR analysis revealed that a local uplift was take place in a part of Owakudani from May to June. After these, on June 30, eruption occurred at the nearest neighbor of the locally uplifted area in Owakudani. Though the eruption was tiny, a group of vents was created. Since July the activities were going down, the extension of the GNSS baseline was stopped and the seismicity decreased.
Associated with phreatic eruption, the type of eruption expected at Owakudani, hydrothermal activity often causes thermal demagnetization of underground rock in rather shallow place and results in magnetic change on the surface. For Kusatsu-Shiranesan and Meakandake where phreatic eruption occurred in recent years, observed magnetic variation of total intensity is one of indices used for assessment of the volcanic activity. For Owakudani, the magnetic intensity is also thought to be a hopeful data for the volcanic monitoring, we carried out repeat observation of magnetic intensity around Owakudani from May to November in 2015.
It was revealed from the observation that the magnetic intensity decreased by about 1nT from July to September, after the eruption, at the stations in the northern part of Owakudani. In the same period, a slight increase of the intensity was possibly occurred at a station in the southern part. These kind of magnetic variation is expected when underground rock get magnetized, and it will be possible by cooling of heated rock. Beneath Owakudani, the rock temperature seemed decreased from July to September. It might be happened by the creation of the vents in the eruption at the end of June and they made the cooling more effective. Assuming the temperature decrease was occurred beneath the locally uplifted area in Owakudani before the eruption, and the depth was 500m from the surface, the obtained magnetic moment was estimated as 2-3 x $10^6 Am^2$.

Keywords: Hakone, magnetic variation, volcanic activity

Volcanic ash erupted from Owakudani fumarolic area of Hakone volcano on June 30, 2015, and its soluble components

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Volcanic ash erupted from Owakudani fumarolic area of Hakone volcano on June 30, 2015, was collected, and their constituent minerals, chemical compositions, and water soluble components were analyzed.
Smectite, pyrite, tridymite, cristobalite, gypsum, anhydrite, plagioclase and quartz were detected in the volcanic ash by XRD and microscopic observation. This mineral assemblage indicates that the volcanic ash was derived from relatively low-temperature alteration zone of the hydrothermal system beneath the Owakudani fumarolic area. The volcanic ash contains relatively lower concentrations of some elements such as Na, K, Ca and Mg than andesitic lava in the Owakudani area (Takahashi et al. 2006), supporting that the volcanic ash was derived from hydrothermal alteration zone. Water soluble components seemed to be derived from thermal water because high amount of Cl^- and SO_4^{2-} (12.2 and 6.6g/kg, respectively) and Cl/S ratio of 5 were detected. Considering that there are thermal waters which have Cl/S ratio of about 2 at depth around 29-36m (Watanuki, 1966) and that of 7-18 at depths around 500m (Oki and Hirano, 1974), volcanic ash seems to be erupted from depths of around 500m below the surface, or more shallow depth.

Keywords: Hakone volcano, phreatic explosion, volcanic ash, hydrothermal mineral, water soluble component

Water quality characteristics of Lake Nyos, Cameroon

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In 1986, Lake Nyos in Cameroon released a large amount of CO_2 and killed more than 1700 residents. Subsequent investigation revealed that the CO_2 is originated in degassing magma and is ascending from the bottom of the lake with thermal water (e.g., Kusakabe et al., 1989; Ohba et al. 2012). Although controlled degassing started at Lake Nyos in 2001 and have resulted in reducing CO_2 content of the lake (e.g., Kusakabe et al. 2008), investigations regarding chemical components except CO_2 content is also important to ensure gas disaster prevention.
In this study, chemical compositions of the water samples collected from various depths in the lake Nyos and volcanic rocks collected from lake rim were analyzed. TDS of the lake increases with depth. The ionic dominance pattern for cations is Fe^{2+} > Mg^{2+} > Ca^{2+} > Na^{+} > K^{+} at the bottom of the lake, whereas the anion is dominated mainly by HCO_3^- with only a very small amount of Cl^- and SO_4^{2-}. Except for HCO_3^- derived from CO_2, whose origin has already been described, the concentration of dissolved components are 40 ~ 380 mg/L and Na/(Na+Ca) weight ratios are about 0.3 ~ 0.4, indicating that the water quality of the lake is affected by water-rock interaction. Good correlation was observed between chemical compositions of lake water and whole-rock compositions of the rock samples, supporting this inference. Assuming that the chemical components of the lake water are derived from rock dissolution, the solubility of the elements seem to be basically controlled by the ionic potential (Z/r), elution rate of elements of large Z/r (e.g., Al, Ti and Cr) were small compared to elements of small Z/r (e.g., Na, K, Ca, Mg, and Mn). Additional study in consideration of pH condition and equilibrium state of minerals is important to determine the water-rock interaction processes that affect the water quality.

Keywords: Cameroon, Nyos, Crater lake, Limnic eruption, Water quality

Change of Izu Ohshima GNSS height at 2012

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Takayama et. al.(2015) showed the change of GNSS height around Mt. Mihara. After that, all stations in Izu Ohshima is change in GNSS height at 2012.
On all stations in Izu Ohshima, we approximate GNSS height by line from 2009 to 2011 and after 2013. Rate after 2013 minus rate from 2009 to 2011 are the changes at 2012. These changes are large near north of caldera. They are small at north and south island.
We plot the changes against distance from north of caldera. We plot a rate of rise by Yamakawa-Mogi model of depth 5km on this graph. If we set 2.1*10^6 square meter per year, the changes coincide with the rate of rise by Yamakawa-Mogi model. This means that the rate of rise increases 2.1*10^6 square per meter at 2012.

Keywords: GNSS, Height, Izu Ohshima Island

Volcanic activity in Nishinoshima volcano 2013-2016

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Since activity starting on November 20, 2013, a volcanic activity at Ogasawara Islands (Bonin Islands) Nishinoshima volcano has continued an active volcanic activity for about 2 years.
But the volcanic activity was declining finally, and the eruptive activity wasn't confirmed any more by an investigation after 22 December 2015.
The Japan Coast Guard has been carrying out observation of Nishinoshima volcano in cooperation with the Tokyo Institute of Technology since the volcanic activity’s restart was confirmed.
A detailed report is done about a change in the activity style of the eruptive after the flank eruption of volcanic cone on 7 July, 2015.
There was a lava flow which reaches an east-south side coastline from the northeast side of the formed volcanic cone on the south side of Nishinoshima from after May, 2015 to around July.
The volcanic activity of this period has been eruption successively.
And , the summit eruption became dormant at early morning on 6 July, 2015 , Japan coast Guard survey vessel was investigating.
And flank eruption has begun from the volcanic cone’s north side around 10:50 about 4 hours later.
Next day, The eruption resumed from the summit crater of volcanic cone at early morning on 7 July, 2015.
The two big craters were formed to the top of the volcanic cone as a result of flank eruption on July 6-7.
It's the activity style in intermittent eruption of the strombolian type from the activity that strombolian eruption is continued more continuously, it changed.
There were no expansion of land area for lava flow like before on July 2015, because the volume of lava decreased.
The vulcanian eruption was a sound with eruption and infrasonic wave in airplane on 17 November, 2015.
Eruptive activity wasn't admitted in December, 2015, and the temperature in the crater also fell to the surrounding temperature level.
There are no reports of the eruptive activity current as of January, 2016.

Keywords: volcano, Nishinoshima

Precision surveying of the lava flow in Nishinoshima volcano -What has been found from the ultra- low-altitude imaging by the UAV? -

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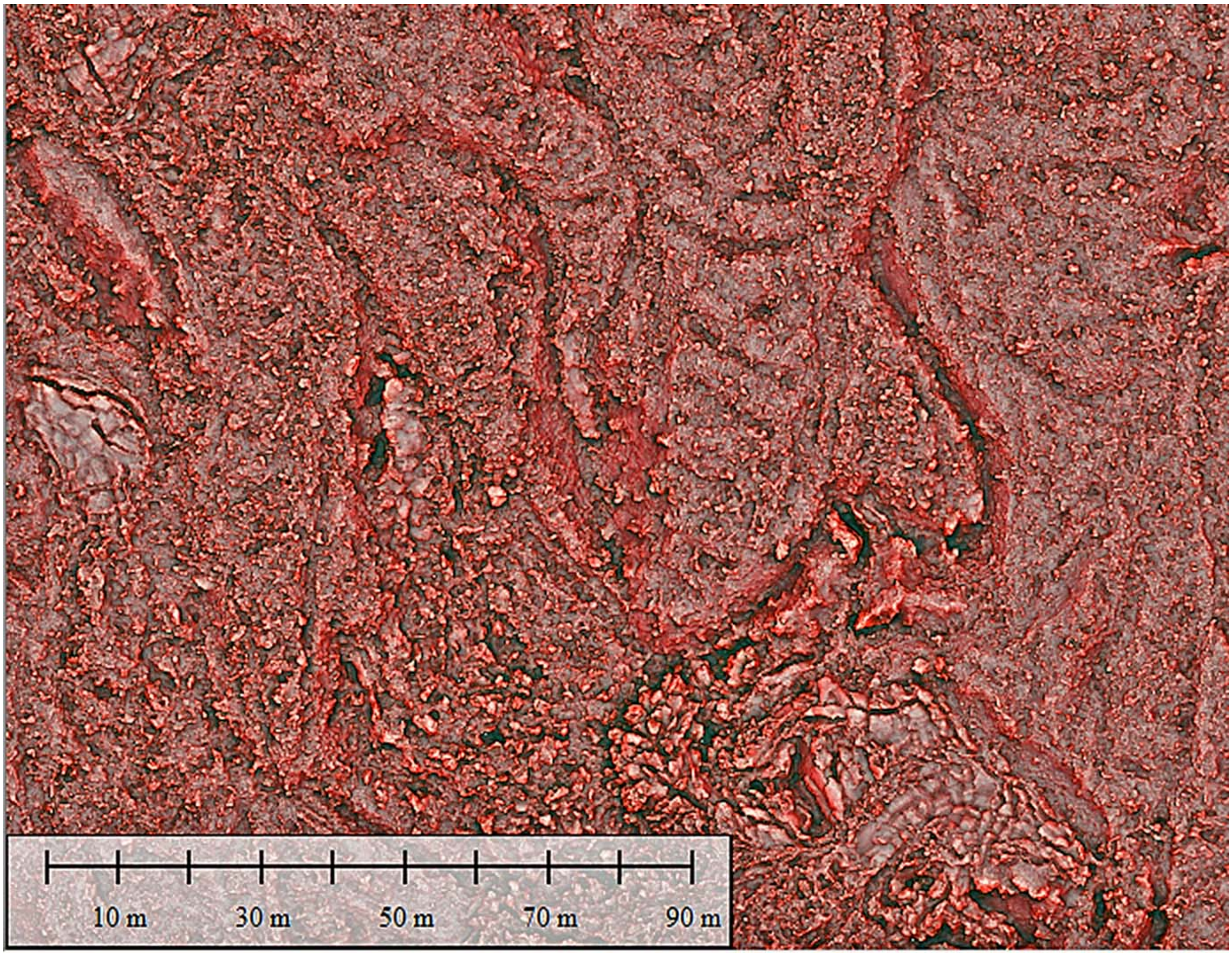
The Nishinoshima volcano started eruption in November, 2013. Because Nishinoshima was a remote island, the surveying interval was long with several months from several weeks, and the detailed observation of the lava flow situation was difficult. Japan Broadcasting Corporation (NHK) had photographed Nishinoshima island in its active volcanic activity, in a period from May to July, 2015 (Table 1). On May 9th and 12th, NHK launched unmanned aircraft from Chichi-jima island of Ogasawara Islands, and captured images of the island with a single-lens reflex camera for pre-test of a research project. From June 28 to July 3, NHK launched an unmanned helicopter (UAV) from a ship anchored at the point of 4 km from the crater and captured movies and images of the lava flow and the crater in the eruption. The unmanned helicopter had recorded imagery of high resolution and high quality, including 4k video, at 120m flight height above the ground. This project had been collected massive data of Nishinoshima island in its active volcanic activity. From the world-wide point of view, it can be said that this is the first time of collecting repeatedly imagery of volcanic activity from very close position, including lava flow and erupting crater, in a short period of time. In this study, we made 5cm and 25cm DEM based on these images using the SfM (Structure from Motion) software and generated a red relief image map. This resolution has enough precision in order to grasp the width of the crack that occurred on the lava flow surface and the change. We distinguished small impact crater, volcanic bombs, depression fake crater and hornito around the scoria cone. And we distinguished two types of lava flow, one is a'a lava flow and another one is branched tube type lava flow. The a'a lava flows have compressed ridge and levee in surface. The tension cracks are developed on surface of branch tube type lava. The width of cracks become to wide in 4days. And the front of this lava flow was proceeded to a sea shore at the same time.These evidences suggest to inflation of lava flow triggered by molten lava saturation in a tube. This type structure of the branched inflated lava tubes were founded any fields, (1) Jyo-ga-saki shore of Izu Peninsula, (2) 2nd lava flow of Taisho lava in Sakura-jima volcano, (3) Aokigahara lava field of Fuji volcano. The flow speed of a'a lava are faster than branch type lava.
Acknowledgment
This result of paper is a part of collaborative research with Japan Broadcasting Corporation (NHK). We are deeply grateful to NHK collected and provided valuable data from the aspects of enhancing volcanic research and spatial technology.

Keywords: photogrametry, UAV, lava inflation


10 m
30 m
50 m
70 m
90 m

Shallow Seismic Structure at Nishinoshima Volcano

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Nishinoshima island is located at about 1000 km southward from Tokyo, belonging in the volcanic front of the Izu-Ogasawara (Bonin) arc-trench system. Since an eruption resumed at southeast side of the Nishinoshima mainland in November 2013, for the first time in the almost 40 years, the area of nishinoshima expands taking in Nishinoshima mainland with a large amount of volcanic lava. Although volcanic activity calms down gradually as of January 2016, it still continues.
Investigating underground structure around Nishinoshima becomes important to understand the volcanic activity of Nishinoshima. The information of underground structure of volcanoes can be expected to elucidate the transfer systems of magma and volcanic fluids accompanied by volcanic activity. Also, we can determine the location of volcanic earthquake more precisely using estimated seismic velocity structure.
Seismic explorations have been done such as Fuji volcano, Aso volcano and Kuchinoerabujima volcano. The seismic exploration results, for example at Aso volcano, revealed the existence of high seismic velocity body centered on the volcanic crater. Additionally Japan Coast Guard (JCG) carried out several ocean bottom seismographic observation at submarine volcanoes such as Myojin-sho and Fukutoku-okanoba. The results of survey at Fukutoku-okanoba showed there is the material which attenuates seismic waves under the volcanic body. However there is not so much detailed information about seismic velocity structure of Nishinoshima volcano.
JCG carried out overall geological and geophysical surveys to elucidate the present volcanic activity in detail using S/V *Shoyo* during June to July 2015. The survey includes seismic refraction measurements, using Ocean Bottom Seismograph (OBS) and airgun system, and the seismic reflection measurements using a single channel seismic streamer. The purpose of this measurement is to estimate preliminary shallow crustal seismic velocity structure around Nishinoshima. In this report, we show the results of fan shooting and seismic refraction measurement around Nishinoshima volcano.
In this survey, we shot totally 11 survey lines which went along right over OBSs deployed by JCG, Earthquake Research Institute (ERI) and Meterological Research Institute (MRI). There are 2 or 3 OBSs in every survey line and the survey line lengths are almost 20 km. Total airgun volume is 3000 (1500x2) inch^3 (about 49 L) and shot interval is 40 seconds.
Based on the results of fan shooting used each OBS’s record section, we found the area where the amplitude of seismic waves attenuate depending on the direction of traveling waves. This area might exist just under the volcanic body of Nishinoshima volcano.
In the seismic refraction measurements, the first arrivals of refracted seismic wave of about 4 km/s were observed in each record section at epicentral distances between 3 to 8 km. Many seismograms recorded the first refracted arrivals at the epicentral distances over 10 km. In some record sections, we also found the later phases of around 2 km/s which can be interpreted as reflected seismic signals. According to the preliminary P-wave velocity model obtained by the 2-D ray tracing method, a layer of 2 km/s as the topmost layer has a thickness of around 1.5 km. We could explain observed travel times if the P-wave velocity of the underlying layer will be around 4.5 km/s.

Keywords: Nishinoshima, Shallow crustal structure, Seismic refraction measurement

Estimation of source location of volcanic earthquakes beneath Nishinoshima volcano applying the envelope correlation method to ocean bottom seismometer data

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Meteorological Research Institute deployed five ocean bottom seismometers (OBS) around Nishinoshima volcano to investigate the source location of volcanic earthquakes. The observation period is from June 21 to October 2, 2015.
As a preliminary analysis, we picked up 45 earthquakes from 30-minute-long OBS data (2015/6/21 07:00:00-07:30:00), converted them into RMS envelope in 4-8 Hz, and estimated source locations applying the envelope correlation method (Obara, 2002). Most earthquake sources located almost right beneath the volcano with a wide distribution in a vertical section. A further analysis is expected to figure out more precise source locations of volcanic earthquakes and to reveal the eruption processes.

Keywords: Nishinoshima volcano, source location, envelope correlation

The re-analysis of the EM data associated with the 2014 eruption, Aso volcano.

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On Aso volcano, magmatic eruption was occurred at Nov. 2014, first time in 21 years. Around the Nakadake 1st crater, which is the most active crater of Aso volcano, we conducted continuous geomagnetic field observation (since 1991). From these observations, we obtained the data which suggest the subsurface thermal state had drastically changed before the beginning of the eruption. From the continuous geomagnetic field (total field) observation, significant temporal change was observed. This temporal change began from Oct. 2014, one month before the eruption. The sense of this change is demagnetization and it suggests subsurface temperature was increased. This change was continuing to the end of Apr. 2015. In our study, we re-analysed the data of the temporal change of total field on the period of Oct. 2014 to Apr. 2015. In this study, we tried to decompose the observed change into regional geomagnetic change, periodic change and smoother trend with removing the noise influence based on the method proposed by Hujii and Kanda (2008). As the result, we obtained a clear trend which means the total field change related to the volcanic activity in very high resolution. From this result, it is possible to obtain important information about the magma movement related to the eruption of 2014. In our presentation, we will show the detail about our observation data and results of the data decomposition as well as the model for the movement of subsurface heat sources which is derived by the equivalent source analysis.

Keywords: geomagnetic total field, volcano-magnetic change, thermal demagnetization

Compositional variation of Holocene volcanic products from the northwestern part of Aso central cones

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We described the petrography of Holocene volcanic products from the northwestern part of Aso central cones and compared their bulk rock compositions with the result of paleomagnetic study. We examined their genetic relationship by fractional crystallization model.

Holocene volcanic products of this area gradually changes to more unfractionated magma type, from Kishimadake to Ojodake, Komezuka, with time. Paleomagnetic directions determined by Yato et al. (2013) showed that the simultaneous eruptions occurred at different volcanoes. They also showed that the three volcanoes repeatedly erupted after intervals of quiescence. Tamai (2015MS) divided lavas of Kishimadake, Ojodake and Komezuka into 5 stages using magneto-stratigraphy. Kishimadake lava of stage 3 is different from that of stage 1. One is similar to Komezuka lava and has an intergranular texture. The other has an intersertal texture. Mineral assemblage is the same. Ojodake and Komezuka lava show little change in composition, mineral assemblage and texture throughout all stages.

All of the three range from 1.7 to 2.3 in FeO*/MgO ratio with 51.0-53.5 wt.% SiO_2. Ojodake and Komezuka lavas differ in FeO*/MgO ratio even though they have the same SiO_2 content. It suggests that steady-state recharge and eruption occurred in the magma supply system for several hundred years. In addition, coeval lavas from different volcanoes, of different chemical compositions, indicate multiple magma chambers were present. Because the Rayleigh fractional crystallization model did not reveal parent-daughter pairs, simple fractional crystallization of the observed phenocryst assemblage do not account for compositional variation of Holocene volcanic products.

Keywords: Aso, central cones, post-caldera volcanism, Holocene, paleomagnetic directions, chemical compositions

Continuous soil diffuse CO_2 flux measurement at Aso volcano, Japan

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Carbon dioxide is a major volcanic gas component which gives important information for monitoring volcanic activities. This gas is not only emitted as volcanic plumes from craters and fumarolic areas but also widely emitted through soil surface of volcanoes as invisible emission called "diffuse degassing". There are several advantages for monitoring the soil diffuse degassing, because the soil gas usually do not have corrosive acidic gases and its temperature are generally low. Thus, it is much easier to carry out continuous monitoring compared to that for high temperature fumarolic gases. Many precursory changes have been reported related to soil diffuse flux of CO_2 prior to the volcanic eruptions or to significant changes of volcanic activities.
We set up a CO_2 flux station (West systems, Italy) for continuous monitoring of soil CO_2 diffuse degassing at Aso volcano, Japan, in early Jan. 2016. The station was set about 1 km south-west from the rim of a currently active crater of Mt. Nakadake near Hondo observatory of Kyoto University. The station is powered by solar panel system and measures the soil CO_2 flux every hour by the accumulation chamber method together with various meteorological parameters such as air temperature, air pressure, humidity, precipitation, wind speed and etc. At least until mid Feb. 2016, the CO_2 flux has been low ranging below 0.28 moles/m^2/day. In the presentation we will introduce our measurement at Aso volcano, discuss influence of various meteorological elements to the diffuse CO_2 flux, and compare the flux with the volcanic activities of Aso volcano.

Keywords: Aso volcano, volcanic gas, CO2 diffuse degassing

Temporal variation of source locations and occurring conditions of continuous tremors at Aso volcano

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In November 2014, magmatic eruptions started at Aso volcano after 20 years dormancy. About one year before this eruption activity, a new eruptive vent was opened and several ash emissions occurred in January 2014. At this period, significant changes in both amplitude and peak frequency of continuous tremors had been recognized. The amplitude of 5-10 Hz band-filtered seismograms recorded at station SUN increased gently until December 22, 2013 (Stage I). The peak frequency increased from 2 to 3 Hz. Until December 30 (Stage II) the amplitude increased rapidly (3 Hz). After a sharp amplitude decrease on December 30, the amplitude took high value until January 2, 2014 (2 Hz, Stage III). From 2 to 3 January it reduced sharply. The amplitude increase similar to Stage I was observed for 10 days (3 Hz, Stage IV). From 13 to 20 January, it took very low value with 1.8 Hz peak (Stage V).

In this study, we focus this two-months stage of volcanic activities to understand source process of the continuous tremors.

For locating tremor sources, we perform a grid searching using a spatial distribution of amplitude ratios of the tremors recorded at five seismic stations around the crater. Estimated source locations distribute from the ground surface to a depth of 700 m beneath the crater and migrate through the analyzed period. The source depths in Stage I to IV are 260, 180, 190, 350 m, respectively. Distribution of these source locations connects the ground surface and the upper end of the crack-like conduit (Yamamoto et al., 1999). It also passes through a low resistivity area (Kanda et al., 2008). This may indicate the shallowest pathway of volcanic fluids, which has never been revealed.

Julian (1994) suggested that continuous tremors caused by oscillation of channel walls through which fluids pass. Using this model, we find that both amplitude and peak frequency of the oscillation depend on conditions of both channel thickness and output fluid pressures. For instance, increase of channel thickness makes amplitude to increase. The increase in the thickness can be regarded as expansion of a fluid pathway according to increase of fluid supply (Aki et al., 1977). Additionally, as an output pressure increases, both amplitude and frequency increase as well. Increase and decrease of the output pressure can relate to choke and widening of the pathway, respectively.

Based on all information aforementioned we suppose qualitatively temporal variation of source locations and occurring conditions of the continuous tremors at Aso volcano as follows. In Stage I, we observed the increase of both tremor amplitude and peak frequency. This was caused by increase of fluid pressure in the pathway to reflect supplying of larger amount of volcanic fluids. In order to satisfy this pressure increasing, a conjunctive portion at the upper edge of the crack-like conduit that connects to a narrow pathway into the crater was widened. In Stage II, observed increasing of amplitude was owing to an expansion process of the whole part of this narrow pathway. At the end of this stage when we observed both amplitude and frequency dropped, pressure in the upper part of the pathway decreased due to an opining of the vent. In Stage III, the pathway was still enlarging to transport the fluids, which caused large tremor amplitude. The fluid supply then decreased. We detected it as a sharp decrease of tremor amplitude and increase of the peak frequency. In Stage IV, fluid supply increased again. To satisfy the increase of the fluid pressure, the upper part of the crack-like conduit was expanded again. However, observed amplitude

was not so large rather than the Stages II and III because establishment of the pathway had been already completed in those stages. At the end of this stage, occurrence of ash eruptions led to pressure drop in the shallower portion of the pathway so that we could detect both the amplitude and frequency decreased.

Keywords: volcanic tremor, Aso volcano

Monitoring volcanic long period tremors from Aso volcano in 2014-2015

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Introduction

Aso volcano is one of the most active volcanoes in Japan and has erupted repeatedly more than a thousand years since the dawn of history. It has been proposed that long period tremors (LPTs) are caused beneath Aso volcano by the elastic interaction between the volcanic gasses or ash passing the crack-like vent, and the wall of the vent. This LPTs have a dominant period of about 15 s. By monitoring the LPTs from Aso volcano for two years from 2014 to 2015, we revealed the relationship between LPTs and eruptive activities.

The monitoring of LPTs

We used three-component broadband seismograms from seven F-net broadband seismograph network stations operated by National Research Institute for Earth Science and Disaster Prevention around Aso volcano. First, we investigated the changes in daily power spectrum for each component and each station. The continuous signal with a dominant period of 8-12 s was observed at time periods from October 2014 to April 2015, and from September to October 2015. These periods well agree with Strombolian eruptions and occurrence of volcanic tremors reported by Japan Meteorological Agency. Furthermore, this signal was not observed in the same season in the previous year. Therefore, it is interpreted as LPT signal rather than seasonal changes of microseisms. The signal amplitude was dominated in the radial and vertical component measured from Aso volcano, and this suggests that it was Rayleigh waves of the LPT.

Then, we detected LPTs by applying the matched filter technique. We first selected a LPT event with high signal-to-noise ratio as a template event, and prepared three-component waveforms at the seven stations. We then calculated the cross-correlation coefficient between the template and continuous waveforms, with sliding the time window through the continuous waveforms for two years, to compute the sum of 21 cross-correlation coefficients as a function of time. When the sum of the coefficients exceeded a threshold set based on the median absolute deviation, we detected an event as a LPT. The amplitude ratio between the template and detected events were also estimated by a waveform fitting method. We also applied the same analysis to records from six stations because a record of one station was unavailable for a period in 2015.

As a result, we detected LPTs with wider dynamic range in amplitudes, including amplitudes smaller than 100 nm/s, which previous study (Sandanbata et al., 2015) excluded from their analysis. In addition, we observed that the amplitude of LPTs dropped sharply only from the end of December 2014 to January 2015 during the continuous eruption from November 25th, 2014 to May 21st, 2015.

Changes in frequency-amplitude distribution

We divided the analysis period into 21 stages based on the trend of the time-series of LPT amplitude and calculated frequency-amplitude distribution for each stage. Previous study (Sandanbata et al., 2015) showed that the distribution follows the power-law distribution rather than the exponential distribution just after the Strombolian eruption in November 2014 and interpreted that the characteristic amplitude scale was lost by the Strombolian eruption. We obtained the similar result during this period. We note that the all stages in 2015 activities show that they follow exponential distribution, and this suggests the peculiarity of the Strombolian eruption in November 2014. On the other hand, smaller LPTs dominated from the end of December 2014 to January 2015 compared to other stages. Japan Meteorological Agency reported that grayish white fumes were observed from November to December 2014 and from March to May 2015, whereas white fumes were observed from January to February 2015. Our result and the reported phenomena indicate that the change in the main component of the fumes from water vapor to volcanic ash had some effect on the amplitude of LPTs.

Keywords: Mount Aso, Volcanic tremor, Long period tremor, Frequency-amplitude distribution, Rayleigh wave

Tilt changes associated with eruptions by the tiltmeter array at Aso volcano.

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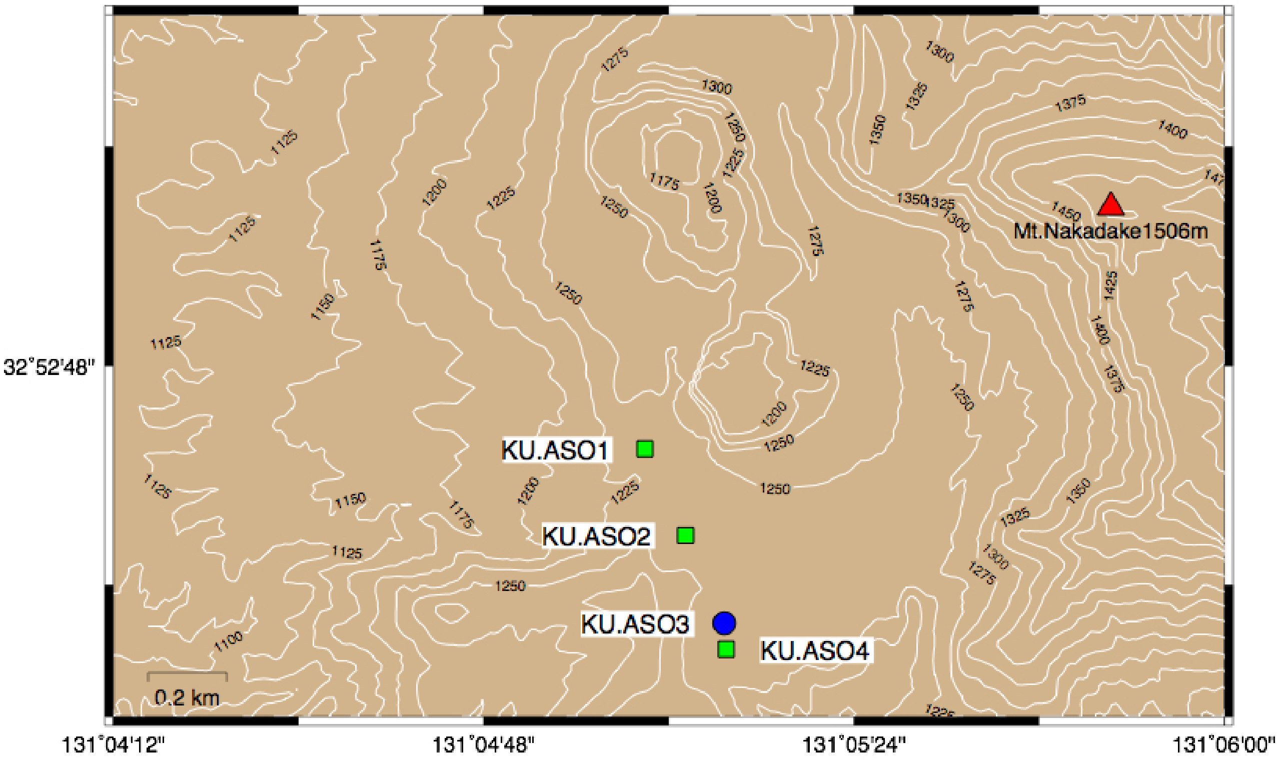
Aso volcano started magmatic eruptions from November 25, 2014. Eruptive activity once became quiet in mid 2015. However, a phreatomagmatic eruption occurred on 14 September 2015, and phreatic eruptions have sporadically occurred untill February 2016. We investigate the space-time variation of pressure sources acssociated with volcanic eruptions in order to understand the eruption process in the shallow volcanic conduit of Aso volcano.
In general, an observation using tiltmeter is arranged so as to surround the volcano, for the estimation of location of pressure sources. In this study, however, a tiltmeter array deployed in a straight line to the first crater of Nakadake, assuming the pressure sources locate beneath the crater. By calculating the cross-correlation of tilt variations recorded at each station, we can estimate the depth change of pressure source with time associated with eruption at the first crater of Nakadake of Aso volcano.
The tiltmeter has been installed three points (KU.ASO1, KU.ASO2, KU.ASO4) to the south of the first crater of Nakadake (Fig.1). At KU.ASO1 and KU.ASO2, the tiltmeters were set in the ground. In addition, we have installed a microphone and a broadband seismometer at KU.ASO1 and KU.ASO3, respectively. The observation started from July 14, 2015, and we successfully observed the tilt changes associated with eruptions of 14 September, 23 October and 7 December 2015.

Keywords: Aso volcano, Tilt array


KU.ASO1
KU.ASO2
KU.ASO3
KU.ASO4
Mt.Nakadake1506m
0.2 km
32°52'48"
131°04'12"
131°04'48"
131°05'24"
131°06'00"

Source depth of Strombolian eruptions at Aso volcano in April 2015

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At the Nakadake 1st crater of Aso volcano, magmatic eruptions had started in November 2014 after 22 years dormancy. This eruption activity lasted until May 2015. It was a first time for us to observe the eruptions using a network of seismo-acoustic sensors deployed around the crater. We have stations equipped with a low-frequency microphone (ACM) and a short-period seismometer (KAF) on the crater rim. They are situated at 260 m SW and 230 m SWW from the active vent, respectively. On the NNW flank of the volcano (830 m distance), a broadband seismometer (UMAB) is installed. In this study, we analyze seismo-acoustic data acquired at these three stations in the 19:00-20:00 JST (GMT+9:00) on 24 April 2015 to estimate source depths of Strombolian eruptions.
At each Stromoblian eruption, characteristic seismo-acoustic signals were observed. They were typically started by a downward phase of low-frequency (<0.1 Hz) seismic velocity to the UMAB station. This wave corresponded to a long period tremor (LPT; Yamamoto et al., 1999, GRL). A couple of seconds later (1.7-5.4 s), higher frequency (5-10 Hz) seismic velocity arrived to the KAF station. Infrasound wave was detected at ACM about 1 s after the seismic arrival to KAF. The infrasound wave (peak frequency is ~0.5 Hz) was started by a compression phase, however in 0.1 s later a high-frequency content (>10 Hz) was added on it. We can recognize a strong positive correlation (R=0.92) between Root-Mean-Squared (RMS) amplitude of the seismic velocity at KAF and that of 10 Hz high-passed infrasound wave at ACM. The time delay between the arrivals of these two signals was 0.93-1.56 s (mean 1.2 s).
To estimate source depth of each Strombolian eruption, we assumed that a space in the conduit through which infrasound wave propagates was occupied with hot volcanic gases. On the basis of a composition (H_2O:SO_2:CO_2=90:4:4; Shinohara, Pers. Comm., 2016) and a temperature data (330-360 K at the vent), the sound velocity inside the conduit was estimated to be 410-430 m/s. We also considered that seismic signals observed at KAF are composed of the P wave (V_P=3.3 km/s; Tsutsui et al., 2003, BVSJ). It resulted in the source depth of each Strombolian eruption to be 70-380 m. This depth is consisted with a shallow region above an upper edge of the crack-like conduit (300 m; Yamamoto et al., 1999, GRL).
We intended that signals of LPT arrived to UMAB was 1.7-5.4 s earlier from the arrival time of high-frequency seismic wave to KAF. Because LPT is resulted from a resonant oscillation of the fluid-filled crack-like conduit beneath the active crater (Yamamoto et al., 1999, GRL), Strombolian seems to relate the source of LPT as well. According to a near-field effect, the phase velocity of the LPT has a value between those of the P and S waves (3.3 and 1.9 km/s; Sudo and Kong, 2001, BV). It indicates that ascending speed from the source location of the LPT, at the center of the crack-like conduit (1.6-1.8 km; Yamamoto et al., 1999, GRL), to the depth of Stromoblian eruption we could estimate (70-380 m) is 300-700 m/s. It is too fast to consider that the volcanic fluids (magma and gases) migrate upward with this velocity. At the present, we interpret it as a pressure wave; it is radiated from the LPT source at the same time of the LPT occurrence and propagates inside the crack-like conduit to the depth of Strombolian eruption. Estimated speed of the pressure wave (300-700 m/s) is accountable either when andesite molten magma (sound velocity is 2.3-2.5 km/s; Murase and McBirny, 1973, BGSA) includes bubbles at a few vol.% (Morrissey and Chouet, 2001, JVGR), or when H_2O vapor steam contains small amount of ash particles (< 10 vol.%). The time delay of 0.1 s between arrival times of the 0.5Hz and >10Hz infrasound waves at ACM may become a clue to understand detailed process of Strombolian eruption at the depth.

Keywords: Aso Volcano, Strombolian eruptions, Aso 2015 Eruption

New fumarole activity at the southwest rim of Ioyama in Kirisima volcanoes, Southern Kyushu

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A new fumarole appeared on the southwest rim of the Ioyama old crater in the Kirisima volcanoes on December 14th, 2015. Previously, two main fumarole zones were active in Ebinokogen site: the Ebino fumarole zone in the west and the Ioyama fumarole zone in the east (Geothermal Research Department, the Geological Survey of Japan (GSJ), 1955). The Ebino fumarole zone was very active from the 1940s to 1960s (Council for conservation of nature of Ebinokogen, 1987). Temperatures were measured by GSJ at depths of 1 m in the Ebino fumarole zone and observed 96°C in 1954. In the 1940s to 1960s, this zone moved to the west, and the activity decreased until 1970s.
The center of the Ioyama fumarole zone is about 0.8 to 1 km to the east of the center of the Ebino fumarole zone (Geothermal Research Department, GSJ, 1955). Records from sulfur mining indicate that the Ioyama fumarole zone has been active before AD 1900. The oldest fumarole temperature was recorded over 80°C in Ioyama measured by Oda Ryohei on August 12th, 1916 (Oda, 1922). Akiko Yoshano described the fumarole in a short Japanese poem in 1929. The temperature of the fumarole in the Ioyama fumarole zone reached between 96 and 120°C in 1954 (Geothermal Research Department, GSJ, 1955). The highest temperature in the Ioyama fumarole zone was recorded as 247°C in March 1975 (Kagiyama, 1979) and five measurements over 150°C in August 1987 (Kagiyama, 1987). However, the activity of this zone declined in 1990s, and we could not find the fumarole in 2008.
The first volcanic tremor was observed on August 14th, 2014 under the periphery area of Karakunidake. And volcanic earthquakes and tremors were observed occasionally from July 2015 (JMA Homepage). A member of the Kirisima nature guide club found a very small fumarole on the afternoon of December 14, 2015 on the southwest rim of Ioyama old crater. A fumarole had previously been identified at this location in the Ioyama fumarole zone. The fumarole temperature was 80°C on this day. We observed temperatures between 93 and 96°C in the fumarole on December 25th and 27th. This new fumarole and high temperature area has continued to expand to the north and south of the original location as of February 2016. We are monitoring changes in the temperature, direction of movement, and location of the fumaroles.
Observation members of Kirisima nature guide club: Kentaro Haraguchi, Takeji, Nagatomo, Takamichi Higashi, Midori Baba, Hideaki Yoshinaga.

Keywords: Kirisima volcanoes, Ioyama, fumarole

Chemical and isotopic composition of the fumarolic gas sampled at Mt Iwoyama, Kirishima volcanic area, Japan

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Introduction
Mt Iwoyama is one of the active volcanoes in Kirishima volcanic area, located on the northern flank of Mt Karakuni. Mt Iwoyama was formed at the eruption in 1768 (Imura and Kobayashi, 2001). According to the observation by Japan Meteorological Agency (JMA), in the early of April 2014, the number of volcanic earthquakes increased. In July 2015, volcanic tremors occurred several times. On 15^{th} Dec 2015, a new discharge of fumarolic gas was noticed on the top of Mt Iwoyama. Those observations indicate the increase of volcanic activity of Mt Iwoyama. In general, the composition of fumarolic gas changes along the progress of volcanic activity. We sampled the newly discharged fumarolic gas on 22th Dec 2015 and report the analytical result with interpretations.
Sampling of fumarolic gas
The position of fumarolic gas was N31deg56min48.3sec, E130deg51min10.5sec. The surrounding area of fumarlic gas was covered with whitish altered rock. The temperature of gas was 97.2C. No fumarolic gas other than the observed one was noticed.
Results and discussions
The concentration of HCl was lower than the analytical detection limit. The SO2/H2S ratio was 0.027, similar to the value in 1994 (Ohba et al., 1997). The H2O-CO2-S ternary composition indicates the CO2 enrichment compared to the gas in 1994. The isotope ratio of H2O (dD) was -91 per mill, lower than -55 and -80 per mill, the values of two fumarolic gases in 1994. A part of water vapor in the observed fumarolic gas seems to be removed by the condensation before the discharge at fumarole, because the isotope ratio was low and the fumarolic gas has appeared at the place with no discharge of fumarolic gas, which means the channel of volcanic gas in crust was cool and it removes the enthalpy of water vapor. The H2O-CO2-S ternary composition and isotopic ratio of H2O can be estimated with the calculated addition of H2O removed by condensation. The estimated composition and ratio were similar to the fumarolic gases in 1994 and 1991 at Mt Iwoyama. The N2-Ar-He ternary composition indicated He enrichment relative to the gases sampled in 1991 and 1994. Kita et al (1993) reported the He enriched endmember in fumarolic gases at some volcanoes in south-east part of Japan such as Mt Unzen-Fugendake. If the He enriched endmember is contained in the sampled fumarolic gas, a magma should be involved with nature different from the degassing magma in 1994. Because the number of sampled fumarolic gas is only one, we need to continue the sampling and analysis to confirm the N2-Ar-He ternary composition.
Acknowledgements
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Keywords: Active volcano, Volcanic gas, Geochemistry

Volcanic tremor recorded on two seismic arrays at Kirishima volcano, Japan

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The Kirishima volcano complex is a group of more than 20 volcanoes in southern Kyushu Island, Japan. The 2011 eruption of Shinmoedake, one of them, was preceded by phreatic events on August 22, 2008 and continued until September 7, 2011. After that we found no remarkable volcanic activity at the volcano. Recently, however, it is observed that fumarolic gas is rising at Ioyama and crustal deformation studies point out ground uplift around the area. Because volcanic earthquakes and tremors also occurred, it is necessary to pay attention to change on the activity. Volcanic tremors are considered to be oscillations that occur in the magma supply system. Therefore, it is important to investigate location of their source and characteristics for understanding the conditions and processes of volcanic activity. We carried out two seismic array observations at Kirishima volcano to reveal source location of volcanic tremor.

It is difficult to locate tremor sources by conventional methods using travel times because we cannot pick the arrival time correctly. One useful method of estimating the source locations is array analysis, which uses data from a dense seismic network in small area. Generally, a seismic array can decompose waves approaching from many directions and determine the slowness of each wave. Although location of the source cannot be uniquely determined by only one seismic array, multiple array enable us to estimate the source location. We deployed two seismic array on August 30, 2014. One consisted of 7 seismometers located near Ohata pond 5 km away from Shinmoedake crater, and the other consisted 7 seismometers located at Shinyu hot springs 3km away from the crater. They were installed with a sensor interval of 200-350 m, and signals from the seismometers were recorded by a data logger with 250 Hz sampling frequency. We use the combination of two array to determine the tremor sources. Moreover, we can also detect temporal change by array analysis.

From August 30, 2014 to October 5, 2015, two volcanic tremor were recorded at our site. We analyzed the tremor which occurred on July 26 at 9:23, 2015 and its duration was about 150 seconds. Peak frequency of the tremor was about 2-3 Hz. As the result of semblance analysis with 2-4 Hz band-pass filter, we found that the tremor was radiated from WSW direction to Ohata array and from north direction to Shinyu array, corresponding to Ioyama area.

Keywords: Kirishima volcano, volcanic tremor, seismic array

Continuous relative gravity observation at Sakurajima Volcano: Short-period gravity changes before and after eruptions

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Mass movement in a volcano leads to minute gravity changes on the ground, along with crustal deformations. Since the amplitude of the gravity changes depends on the density of the mass moving in the volcano, gravity observation is useful to directly understand the mechanism of the crustal deformations, such as melt supply from the deep underground and magma degassing in a magma chamber.
In Sakurajima Volcano (Kagoshima Prefecture, Japan), crustal deformations have been observed to discuss preparation processes for eruptions with broadband time periods from seconds to years (e.g., Iguchi et al., 2008; Hotta et al., 2016). Okubo et al. (2013) also collected absolute gravity values at Arimura (2.1 km south-southeast from the Showa crater of Sakurajima Volcano) continuously, and observed the 10-micro-Gal gravity decrease associated with the magma ascent in a volcanic conduit. However, they only focused on the absolute gravity changes with the period of more than a few days, because the short-period absolute gravity values they collected were noisier than the long-period ones. Precise continuous gravity changes should be collected with the high sampling rate, in order to understand broadband activities of Sakurajima Volcano in terms of mass movement.
We were thus motivated to discuss the short-period processes of mass movements in Sakurajima Volcano, using the continuous relative gravity data sampled every one minute. The gravity data were collected by a Scintrex CG-3M relative gravimeter at Arimura Observatory from September 2010 to December 2015. The gravity data was dominated by several disturbances such as the instrumental drift, the long-period tidal effect with periods of more than a day, and the short-period tidal effect with periods of less than a day, which should be corrected from the original gravity data to retrieve gravity signals associated with volcanism. We first corrected the gravity changes due to the instrumental drift and long-period tides, by subtracting synthetic gravity changes expected by a spline function, which was calculated from the two-day average values of the original gravity data. We also corrected the short-period tidal effect by a tidal analysis software, BAYTAP-G (Tamura et al., 1991). Moreover, we reduced the effect of ground vibrations by stacking the two-day-long gravity data, which was cut off from the corrected gravity time series in 2013 and 2014 on the condition that the median time of the two-day window corresponds to the time of an eruption with a volcanic plume of >3000 m altitude. Note that we individually analyze the gravity data during the non-explosive eruption at 10:18 JST, 26 September 2013, because the small ground vibration enabled us to recognize volcanic gravity signals directly.
The stacked gravity data for the 2013 eruptions showed a slow decrease of about -20 micro-Gal since 12 hours ahead of the eruptions. The stacked gravity data for the 2014 eruptions also showed a rapid increase of about +30 micro-Gal in 30 minutes just after the eruptions. In addition, whereas no significant tilt variations were observed during the eruption on 26 September 2013, the simultaneously obtained gravity data showed a slow decrease since about 5 hours before the eruption, and the gravity value returned to the original level just after the eruption. These gravity changes can be explained by the inflation/deflation of a magma chamber below Sakurajima Volcano or the ascent/descent of magma mass in a volcanic conduit. In this presentation, these possibilities will be discussed quantitatively to understand the short-period process of mass movement in Sakurajima Volcano.

Keywords: relative gravity, gravity change, Sakurajima Volcano, magma, short period, density

Spectral Ratio Analysis of Explosion Earthquakes at Sakurajima Volcano

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Sakurajima volcano has been quite active, and hundreds of small explosions of vulcanian type occur every year, throwing ash to heights of up to a few kilometers above the mountain. Sakurajima volcano generates many explosions with various sizes, but we still have not well understood what physical parameters control the magnitude of explosion. In the present study, therefore, we investigate the source characteristic of explosion earthquakes that are associated with vulcanian explosions at Sakurajima volcano.
We analyze explosion earthquake waveform that are recorded by JMA for the two years from 2012 to 2013. The seismogram are recorded by short period seismometers with a natural frequency of 1 Hz and a sampling frequency of 100 Hz. We analyze Up-Down (U) component at SRB station which is located at a distance about 2 km from the active crater (Showa crater).
We reduce the site effect and propagation effect in the observed seismogram by using spectral ratio method to retrieve the source characteristic of explosion earthquake. We classify the explosion earthquake waveform by using RMS amplitude into 4 classes. The RMS amplitude is calculated for about 400 s from the onset of the earthquake. The RMS amplitude ranges up to 470 x10^-3 nm, and we divide the explosion earthquakes into class I (0 nm - 30 x 10^-3 nm), class II (30 x 10^-3 nm –60 x 10^-3 nm), class III (60 x 10^-3 nm –90 x 10^-3 nm) and class IV (90 x 10^-3 nm –150 x1 0^-3 nm). We calculate the spectral ratios of class II, III and IV to the smallest class (I). We calculate the spectral ratios by setting a time window every 10 sec from the onset to coda wave.
The obtained spectrum amplitude ratio can be described by a flat level at low frequency range (0 Hz -1 Hz) and that at high frequency range (4.5 Hz –10 Hz). The spectrum amplitude ratio gradually decreases in the intermediate frequency range (1 Hz - 4.5 Hz). The corner frequencies at 1 Hz –4.5 Hz does not change significant (change slightly) for the ratio of classes II, III and IV. Analysis of direct waves that begins from the onset for 10 sec show the following characteristics: Ratios at low frequency range for classes III and IV are about 1.6 and 3 times larger than that for class II, while ratios at high frequency range for class III and IV are about 1.3 and 2 times larger than that for class II. Analysis of coda waves that begins 50 sec from the onset show the following characteristics: Ratios at low frequency range for classes III and IV are about 1.4 and 1.9 times larger than for class II. On the other hand, ratios at high frequency range for class III and IV are about 1.06 and 1.1 times larger than that for class II. The ratios for coda waves are slightly smaller than those for direct waves, which implies differences in the source processes between the initial explosion and following continuous ash emissions.

Keywords: Spectral Ratio Analysis, Sakurajima Volcano, Explosion Earthquake

Temporal variation of the ACROSS signals during a period from January to August, 2015 in Sakurajima volcano, Japan.

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Quantitative monitoring of magma transport process is essentially important for understanding the volcanic process and prediction of volcanic eruptions. To realize this monitoring, an active monitoring system using a vibration source called ACROSS has been operated in Sakurajima Volcano since September 2012 (Yamaoka et al., 2014; Miyamachi et al., 2013; 2014).

From our previous observational studies, we obviously found that the amplitude and travel times of the daily transfer functions (the ACROSS signal) vary temporally. In particular Maeda et al. (2015) revealed that the amplitude of the ACROSS signals in the later phases became small in several hours before and after explosive eruptions. In this report, we show a long-term temporal change for the ACROSS signals observed with the remarkable volcanic activity that occurred in Sakurajima volcano on August 15, 2015.

DATA

Our ACROSS system is composed of two vibrators: one vibrator (SKR1) with a signal frequency range of 7.510Hz +/- 2.50Hz and the other (SKR2) with the range of 12.505Hz +/- 2.50Hz. The seismic signals from the ACROSS sources are routinely monitored with more than 20 permanent and 5 temporal seismic stations in and around Sakurajima volcano. The signals recorded at the seismic stations are deconvoluted with the ACROSS source function to obtain the transfer function between the source and the receivers.

The ACROSS system was continuously operated until 18 August, 2015 after five month failure of inverter system. We successfully replace the broken inverter with a normal one by managing transferring inverters from one source to another. The fixed ACROSS system started operation at the beginning of January 2015, but the operation was suspended on 18 August, 2015 because of the signal contamination to a monitoring seismic station for the volcano. We use the data in 2015 to check the temporal change of transfer functions between the ACROSS source and the seismic stations in Sakurajima island.

RESULTS

We calculated the daily transfer functions for each station by every 1 day stacked data during a period of January to August 2015. Transfer functions in Sakurajima volcano indicate large temporal variation especially in later phase part comparing to the other site such as Awaji or Tokai area where ACROSS system is being operated. In many of the transfer function connecting between the ACROSS source and the stations remarkable change can be seen at the end of July, 2015, though causal relationship to the volcanic event on 15 August is not clear. We also need to make a quantitative investigation on the meteorological effect to the transfer functions.

Reference

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Maeda et al. (2015) Geophys. Res. Lett., Doi: 10.1002/2015GL064351

Keywords: structure, temporal variation, magma

Unknown later arrivals in controlled source seismograms in northern Kagoshima Bay region.

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We will present unknown later arrivals in the controlled source seismograms which detected in northern Kagoshima Bay area, and will discuss their origin and structure in the area.

Project Sakurajima 2008 had been conducted with chemical explosion for the sake of exploring magma system and its background structure on November 2008 (Iguchi et al., 2009). A dataset of first arrival time has been analyzed down to 4km below sea level by Miyamachi et al. (2013) and Tameguri et al. (2012). They presented that velocity is lower inside of Aira Caldera than that of outside.

On the other hand, the seismograms also include following two prominent later arrivals which have never been discussed;

1. The phase arrives on 7 to 8 seconds over the stations in south Sakurajima through Osumi Peninsula,
2. The phase arrives on 8 seconds over the stations in Shirahama through Uranomae in north eastern Sakurajima.

The arrival 1 appears definitely clear in southeast shore of Sakurajima. Its apparent velocity is just above 7 km/s and then is asymptotically closing that of the first arrival. The similar later arrival appears in other seismograms across the same region of the midpoints. The arrival 2 appears definitely clear at Wariishizaki point, north shore of Sakurajima. Its apparent velocity is over 8 km/s. No similar arrival appears in any seismograms across the same region of the midpoints.

Considering those characteristics of each arrival, the arrival 1 is interpreted as PP reflection and the arrival 2 as PS conversion. Then, assuming wave types, interface model for the reflection and the conversion have been considered, which can explain their travel time better. An interface at 11 km below sea level appears better fit with both of their travel times. Moreover, the mid points and the estimated converted points coincide with each other at the central area of northern Kagoshima Bay. The reflection and the conversion occur at the same interface because of the model and their identical apparent velocity.

The central area of northern Kagoshima Bay involves inflation sources beneath, which have been presented by Mogi (1958); Yokoyama (1971); Eto et al. (1997); Yamamoto et al. (2013); and Iguchi et al. (2013). The interface coincides with those inflation sources. It is of interest that the interface at the center of northern Kagoshima Bay can associate with possible deep magma reservoir which feeds magma to Sakurajima Volcano.

Keywords: Volcano, Sakurajima Volcano, Crustal structure, Seismology

Seismic activities with regards to the eruptions of Kuchinoerabujima in 2014 and 2015 observed by V-net network

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Kuchinoerabujima, which is located about 12km west of Yakushima, is a volcanic island. Explosive eruptions occurred at Shindake in Kuchinerabujima in 2014 and 2015. It was reported that a new fissure was generated in the western part of the crater of Shindake in the eruption in 2014, according to Coordinating Committee for Prediction of Volcanic eruption in Japan. In addition to this phenomenon, it is also reported that seismic source time functions with regards to these eruptions are different between the eruptions in 2014 and 2015. The north-south component of the source time function was dominant in the eruption in 2015 although only the vertical component of source time function is dominant compared to other components (Matsuzawa: personal communication). To reveal the relationships between these phenomena and seismic activities, we determined the hypocenters and performed waveform analyses using the data-set by Japan Meteorological Agency (JMA) and National Research Institute for Earth Science and Disaster Prevention (NIED) in this study. We assumed half-space with Vp=2.5km/s as a velocity structure. The datasets are composed of 165 events from July 27, 2014 to August 3, 2014 (before the eruption in 2014) and 958 events from April 15, 2015 to June 4 in the eruption in 2015 (507 events before the eruption and 451 events after the eruption). It was found that the hypocenter distribution before the eruption in 2014 concentrated in the western part of Shindake and the hypocenter distribution before the eruption in 2015 tends to be distributed over north and south direction in the vicinity of Shindake. The locations of these hypocenters are thus consistent with the location of the fissure generated by the eruption in 2014 and the source time function with the dominant component of north and south direction estimated in the eruption in 2015. On the other hand, it was found that the direction of particle motion of events after the both eruptions tends to be consistent with that by both eruptions. Changes of the corner frequency of the events were not observed before and after the eruption, in both eruptions. From the hypocenter distribution before the eruption in 2015, it is thus implied that eruption products moved to the north and south direction, using an existing weak line generated by the events with the distribution of the north and south direction in the vicinity of the Shindake before the eruption in 2015.

Keywords: Kuchinoerabujima, hypocenter distribution, seismic source time function

Quantitative understanding of volcanic activities by a combinational use of geophysical and geochemical data - a case study of magmatophreatic eruptions at Kuchierabu volcano, SW Japan

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Generally, magma ascent to a shallow part of a volcanic edifice induces swarms and crustal deformations. Newly-developed cracks and fractures would promote the magma ascent and release of volcanic gases from the magma. The released gases develop a hydrothermal system beneath the edifice, by mixing with the shallow groundwater. When the gas and heat fluxes increase and/or the ascending magma body encounters the groundwater system, phreatic / magmatophreatic eruptions would be induced because of unstable pressure-temperature conditions of the system.
Geophysical and geochemical data (i.e., seismicity, total magnetic intensity, resistivity, InSAR, GPS, and volcanic gas composition) are powerful tools to understand such the various volcanic activities. Also, numerical simulation programs such as HYDROTHERM and STAR can quantitatively evaluate the pressure-temperature conditions beneath the volcano associated with the hydrothermal activity. Therefore, it is expected that the combinational use of the above data and simulations could quantitatively and precisely evaluate the volcanic activity, which might also improve the prediction of the volcanic activity.
Based on the above concept, a working group was established by the authors, to enable the combinational use of the data for the quantitative evaluation of the volcanic activity. In this study, our group will introduce a case study of the magmatophreatic eruption at Kuchierabu volcano, SW Japan, occurred in August 2014 and May 2015. Numerical simulation of the hydrothermal system using the HYDROTHERM software (Hayba and Ingebritsen, 1994) estimates the temporal evolution of the pressure-temperature conditions after the increased flux of volcanic gase and heat and/or the encounter of the magma body. By combining with the previous studies and observed data [i.e., resistivity structure and demagnetized sources (Kanda et al., 2010), volcanic gas data, GPS, and InSAR], our group will try to quantitatively understand the mechanism of the magmatophreatic eruption

Keywords: Kuchierabu volcano, phreatic eruption, hydrothermal system

A 3-D resistivity model of Kuchi-erabu-jima volcano

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1. Introduction

In Kuchi-erabu-jima volcano, a phreatic eruption occurred on Aug.3, 2014 after the preparation period of about 20 years. The existence of magma was presumed in the shallow edifice by several observational evidences such as a large amount of SO2 degassing and volcanic glows, which resulted in a phreatomagmatic eruption accompanied by the pyroclastic flow on May 29, 2015. In this presentation, we report on the three dimensional (3-D) resistivity model of Kuchi-erabu-jima volcano inferred from reanalysis of the AMT (audio-frequency magnetotellurics) data obtained in 2004, in order to reexamine the preparation zone of phreatomagmatic eruption.

2. AMT data

The AMT data were acquired at a total of 27 sites around the Shin-dake crater during September to November of 2004. A part of the data has already published as the two dimensional (2-D) model along the WNW-ESE measurement line (Kanda et al., 2010). As a result, we found a low resistive zone thinly spreading near the surface of craters, and another conductive zone over the whole edifice at depths of 200-800m. These conductive zones were interpreted as layers containing low-permeable clays which were formed by the hydrothermal alteration. A groundwater layer was located between these low-permeable layers, which was considered to constrain the behavior of variation sources of the geomagnetic field and the deformation. However, we performed a 3-D modeling by using all the data obtained at 27 sites because these results were obtained by two-dimensional assumption, and because the data more than a half was not used.

3. 3-D modeling

The 3-D inversion code developed by Siripunvaraporn and Egbert (2009) was used. Full components of impedance tensor of 15 frequencies between 2 and 3000 Hz (error floor: 5%) were used for calculation. Horizontal mesh size around the Shin-dake crater was set to 40 m and the vertical size was 10-15m, a total of 64×64×66 meshes was discretized. Topographic and bathymetric features were accounted for in the model and resistivity blocks corresponding to seawater were fixed at 0.33 Ωm during the inversion process. Although a detailed resistivity distribution around the craters was obtained at present, it is necessary to examine its sensitivity because the site is unevenly distributed along the several trails. We will report the outline of these results.

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Keywords: Kuchi-erabu-jima, resistivity structure, preparation zone of volcanic eruption

Formation mechanism of the sulfur chimney at Mt. Iwo-dake, Satsuma-Iwojima Is.,Japan

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Mt. Iwo-dake stood on Satsuma-Iwojima Is. is one of the most active volcanos in Japan. Many fumaroles have been active everywhere, and the fumaroles involved significant native sulfur deposits around them. Therefore, many parts of the mountain slopes have been decorated in yellow. In addition, quite high temperature fumaroles up to 900 °C have been observed in the summit crater, so there is a quite rare site where we can access such high temperature fumaroles. Another characteristic of the volcano is occurrence of chimney made up only of native sulfur on the fumaroles. Some of them are growing over 1 m hight. Such suffer chimney has been rarely reported all over the world. In this study we propose how to form such sulfur chimney made on the fumarole. Moreover, we will discuss about physicochemical condition in the volcano based on sulfur isotopic compositions of fumarolic gas and sulfur deposit.

Ground Deformation around the Domestic Active Volcanoes detected by D-InSAR of ALOS-2/PALSAR-2

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ALOS-2, was launched on May 24, 2014, has an L-band SAR (PALSAR-2) in the same way as ALOS/PALSAR. PALSAR-2 is of help to understand of a ground surface state, and its interferometric coherence is highly effective for the crustal deformation observation. Furthermore, PALSAR-2, is also very short repeat observation cycle (14days), has a higher resolution sensor than PALSAR. Therefore, higher resolution data can be acquired and we analyzed more frequently and are expected to be useful for disaster prevention and mitigation. After the calibration period of about half a year after the launch, ALOS-2 / PALSAR-2 data has been published on November 25, 2014. Current operational plan of ALOS-2 / PALSAR-2 is continue to be focused on the accumulation of the base map, but a lot of archive data have accumulated in the around active volcano because of early two years have passed from the start of observation.
We have analyzed the ground deformation caused by the earthquake and volcanic activity at domestic and overseas using ALOS-2 / PALSAR-2 data. And then, our analysis results are provided to each department of the JMA, and are used to the study of volcanic activity evaluation and seismic analysis results. In this presentation, we mainly report on the analysis results of around the domestic active volcano.
Some of PALSAR-2 data were prepared by the Japan Aerospace Exploration Agency (JAXA) via Coordinating Committee for the Prediction of Volcanic Eruption (CCPVE) as part of the project ‘ALOS-2 Domestic Demonstration on Disaster Management Application’ of the Volcano Working Group. Also, we used some of PALSAR-2 data that are shared within PALSAR Interferometry Consortium to Study our Evolving Land surface (PIXEL). PALSAR-2 data belongs to JAXA. We would like to thank Dr. Ozawa (NIED) for the use of his *RINC* software (Ver 0.36). In the process of the InSAR, we used Digital Ellipsoidal Height Model (DEHM) based on ‘the digital elevation map 10m-mesh’ provided by GSI, and Generic Mapping Tools (P.Wessel and W.H.F.Smith, 1999) to prepare illustrations.

Keywords: ALOS-2/PALSAR-2, InSAR, Domestic Active Volcano

Volcanic tremor accompanied with crustal deformation

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Recently, Volcanic tremor accompanied with crustal deformation are observed many volcanoes. We will introduce their data.

Deployment of the automatic Multi-gas stations for volcano monitoring by JMA

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In order to help to monitor volcanic activities, the automatic Multi-gas station systems are going to be deployed at four active volcanoes in Japan by JMA. This station has already been installed at Kusatsushirane and Azuma volcanos. Later this year, more two stations will be installed at two volcanoes, Kuju and Ontake.
This telemetric monitoring system was improved from the prototypal Multi-gas system which had been developed by the Advanced Industrial Science and Technology (Shinohara, 2005). This system can detect five gas components, SO_2, H_2O, CO_2, H_2 and H_2O. This station captures drifted atmosphere involving diffused volcanic gases released from fumarole by pump absorption, not by insertion of pipe to fumarole directly. Though this system cannot measure absolute value of gas concentration, this can get composition ratio based on multiple gas components. There are several studies that change of the composition ratio accompanied by volcanic activity by repeated survey (Ossaka et al., 1980). In the past, gas concentrations have not been monitored continuously by stable-maintained systems in active volcanoes in Japan, so this system is expected to accumulate effective data which contributes to evaluate volcanic activity and to detect premonitory phenomenon for phreatic eruption.
This system is needed to be installed near volcanic crater where gas is generated. At such area, power source and communication line are not prepared. So this has independent power system used solar panels and telemetry system used satellite communications. Observation is once per day and measurement time is 40 minutes at 13:00 every day for electric power saving. However, in the case of gas concentration exceeds the threshold value. Extra-measurement is done up to three times a day. Data is transmitted to headquarters of JMA immediately after measurement then it is supposed to be transferred to the MRI and AIST.

Keywords: Multi-gas system, volcanic gas, phreatic eruption

Installation of geomagnetic total field observation stations to active volcanoes by Japan Meteorological Agency

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Due to the eruption of Ontake volcano on September 27, 2014 which became worst volcanic disaster after the Second World War, Japan Meteorological Agency (JMA) decided to strengthen volcanic observation system for prediction of phreatic eruption. Geomagnetic total field observation was adopted one of the strengthened observation system, because it has an advantage to monitoring of hydrothermal circulation under a volcano. From such process, we decided installation of geomagnetic total field observation stations in 2015 fiscal year at four active volcanoes (Tarumae, Azuma, Ontake, Kirishima) in Japan.

We planned that six Overhauser magnetometers are installed approximately within one km from a target crater at each volcano for monitoring the thermal activity beneath the crater, and one Overhauser magnetometer at the foot of each volcano as reference station. Also, one flux-gate magnetometer to measure three components geomagnetic field is installed at the reference station to correct external magnetic field disturbance such as a magnetic storm. The resolution of the Overhauser magnetometer is 0.01nT, and that of the flux-gate magnetometer is 0.001nT. We adopted solar-battery method as supply system, and it works over one hundred days without solar supply due to snow in winter season. The measurement data is transmitted to JMA using satellite or FOMA communication lines.

We selected the observation sites, where the topography is relatively flat and available sunshine for solar supply, approximately within one km from a crater. To avoid the vehicle noise, the observation sites were separated more than 200 m from a roadway. It is known that the annual variations caused by the temperature dependency of magnetization of rocks or soil around the observation site become big at high magnetic gradient observation site. To do the annual variations as small as possible, we selected less than 20 nT/m of magnetic gradient site by conducting magnetic survey around the observation site.

On the Tarumae volcano, there is a fumarolic activity at the summit lava dome. According to the repeat magnetic survey since 1998 by Sapporo Volcanological Center, JMA, magnetization has been progressing after 2010 beneath the lava dome. We selected the observation stations around the lava dome with reference to the result of the repeat magnetic survey. On the Azuma volcano, there is a fumarolic activity at the Oana crater located the south-east slope of Mt. Issaikyo. According to the repeat magnetic survey since 2003 by Sendai Volcanological Center, JMA, demagnetization has been progressing beneath the Oana crater. We selected the observation stations around the Oana crater with reference to the result of the repeat magnetic survey. On the Ontake volcano, we selected the observation stations around the Jigokudani crater which erupted on September 27, 2014. On the Kirishima volcano, the thermal activity is high accompanying with sometime occurrence of volcanic tremor around the Iouyama crater at Ebino plateau. We selected the observation stations around the Ioyama crater for the purpose of the monitoring of the underground thermal activity around the Ioyama crater.

Keywords: Japan Meteorological Agency, geomagnetic total field, active volcano, hydrothermal system, phreatic eruption, Overhauser magnetometer

Effective utilization of geospatial information for intensified volcano activities

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Japan is one of the volcano-abundant countries in the world. Japan saw volcanic activities frequently occurred in Kuchino-erabujima volcano, Sakurajima volcano, Mt. Aso and Mt. Hakone, gave social influences such as evacuation in 2015. Disaster Mitigation measures such as quick and accurate evacuation, are important in order to protect people’s lives and property from a volcanic disaster. Geospatial Information Authority of Japan (GSI) has contributed to mitigate volcanic disaster damages in recent years, by providing related organs and general public with necessary geospatial information. The author will highlight the effective use of three kinds of geospatial information among which GSI has provided for volcanic disaster mitigation.

The first is geospatial information about crustal deformation. Volcanic crustal deformation caused by movement of magma and vapour is so important information that it infers volcanic activity status under grand. In the case of Kuchino-erabujima and Mt. Hakone, the GSI deployed mobile GNSS observation equipment (REGMOS : Remote GNSS Monitoring System) in order to monitor crustal deformation more accurately. In addition, the result of SAR Interferometry complementarily detected ground surface deformation in an area-wide manner. Local crustal deformation detected at Owakudani, Mt.Hakone by SAR interferometry was considered to speedy volcanic alert level operated by Japan Meteorological Agency. Further crustal deformation enabled volcanic estimation source model to compare current situation with the past eruptions in the case of Sakurajima. The provision of such geospatial information through the Coordinating Committee for Prediction of Volcanic Eruption supported experts’ decision making.

The second is aerial / satellite image. Aerial photo is very important because we can visually understand the damage of disaster. While manned flight just above a volcano is difficult during eruption, effort in taking oblique photo enabled to grasp the situation around crater in the case of Mt. Aso. Aerial photo taken by UAV made it possible to understand the disaster situation in detail. The GSI interpreted denuded land, pyroclastic flow and lahar using UAV images. The GSI also extracted surface change by a volcanic disaster using a pair of Landsat 8 images. Thanks to these geospatial information, we could understand the entire damage.

The third is hazard map and elevation map. They are very important to conduct volcanic disaster response operation. The GSI provided volcanic disaster response maps on which disaster prevention facility is described, relief map and 3D map on which detailed topography is draw. Land Condition Map of Volcano enabled to compare past damage of eruptions. These information is effective for efficiency disaster response.

Geospatial information is essential for effective and efficient volcanic disaster response. In tandem with disaster management organizations, GSI will continuously provide useful geospatial information in support of disaster response, rescue work and restoration activities.

Keywords: geospatial information, crustal deformation, SAR(synthetic aperture radar), grasping the damage of disaster, UAV(Unmanned Aerial Vehicle)

A trial for evaluation of explosivity in monogenetic volcanism using grain size characteristics of pyroclasts

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Monogenetic volcanoes are formed in relatively small and short-duration eruptions, but some of them with explosive phenomena due to magma-water interactions (e.g., Wohletz and Sheridan, 1983). In 1983, Nippana tuff ring in Miyakejima Island was formed by small but explosive magma-water interaction in half a day (Aramaki and Hayakawa, 1984). That was a violence event with base surges (Sumita, 1985). As noted below, this kind of eruption style (i.e., phreatomagmatic) is not included in Volcanic Explosivity Index (VEI) originally. Also, VEI has no resolution in small-scale eruptions. Therefore, we should focus on magnitude-free parameters to assess dangerousness of monogenetic volcanism.

Explosivity in monogenetic volcanism is not well evaluated in the previous work. In the first place, what is "explosivity"? Volcanic eruption can be divided in two types: explosive and effusive. According to Wohletz and Heiken, 2002, the explosive eruption is "in which the expansion of gases determines mass transfer processes" in the point of mass transfer system. The mainstream of classification for the explosive eruption is "Walker diagram" which typed by fall-out tephra thinning rate and grain size (Walker, 1973). Walker, 1980 showed five parameters for explain "bigness" of explosive volcanic eruptions: magnitude, intensity, dispersive power, violence, and destructive potential. Taking into account these parameters, Newell and Self, 1982 proposed VEI to explain explosive character of an eruption in historical times. The specific criteria of VEI are volume of ejecta, column height, and descriptive terms. In this index, phreatomagmatic eruptions including Surtseyan have never been considered originally. Hickson *et al*., 2013 added Surtseyan at VEI 4--5, but it lacks in detail. Furthermore, VEI does not include characteristics of ejecta, such as grain size and shape which represents features of explosions.

This study focus on grain size characteristics of pyroclasts to evaluate the explosivity of monogenetic volcanism regardless of the magnitude of eruptions. I compare the characteristics among three type: magmatic, phreatomagmatic, and rootless. To characterize the grain size, I use fractal fragmentation theory which was applied to a scoria cone by Perugini *et al*., 2011, and median grain size which relates with energy conversion efficiency in the magma-water interaction (Wohletz and McQueen, 1984). In this presentation, I will show a result of trial evaluation of explosivity in monogenetic volcanism especially focusing on a role of external water in eruptions.

Keywords: monogenetic volcano, explosivity, magma-water interaction

