Enhancing monitoring capabilities at Nevado del Ruiz volcano, Colombia, and its magma system inferred from seismic waveform analyses

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Nevado del Ruiz volcano located in the Colombian Andes continues its eruptive activity. To enhance monitoring capabilities at this volcano, broadband seismometers and other equipment were installed by the Science and Technology Research Partnership for Sustainable Development (SATREPS) project in Colombia. Using waveform data from the seismic network, source locations of volcano-tectonic (VT) earthquakes, very-long-period (VLP) events, and tremor were systematically determined by the automated amplitude source location (ASL) system. We also performed tomographic inversion of *P* and *S*-wave arrival times and waveform inversion of VLP events. In this paper, we describe the seismic network and monitoring system at Nevado del Ruiz. We then discuss the magma system beneath this volcano based on our estimated source location distributions, tomographic images of *P* and *S*-wave velocities, and source mechanisms of VLP events.

At Nevado del Ruiz volcano, 12 broadband and 3 short-period seismic stations are maintained. Realtime waveform data are retrieved by the seedlink system. We use an automated event trigger system using seismic amplitudes in a low-frequency band of 0.3-1 Hz. Source locations of triggered events and tremor are automatically determined by the ASL system using high-frequency (5-10 Hz) seismic amplitudes. The estimated source information is accessible through a web system, and manual ASL analysis can be performed by this web system.

Our ASL results indicated that VT earthquakes occurred beneath the northern and southern flanks and the sources of tremor and VLP events were distributed from the summit crater (5311 m) to a depth of about sea level in the NW direction. We found that some tremor episodes showed moving sources along the tremor and VLP source region. Our waveform inversion of VLP signals points to tensile cracks dipping toward the NW direction. Tomographic inversion images displayed that the tremor and VLP source region corresponds to the region with high V_p/V_s ratios, implying the existence of fluids in this region. These results suggest that this source region represents an active crack-like conduit, in which tremor and VLP events were triggered by magma fragmentation processes.

Temporal variations in the resonator size and fluid properties of LP events at Kusatsu-Shirane and Galeras volcanoes

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The fluid-filled crack model has been considered as a model of the resonator at the source of long-period (LP) seismic events. Crack geometry and fluid acoustic properties have been estimated by the comparison between observed peak frequencies of LP events and resonance frequencies of the crack model. Recently, an analytical formula for the resonance frequencies of the crack model was proposed by Maeda and Kumagai (GRL, 2013; GJI, 2017). Taguchi et al. (AGU meeting, 2016) showed that observed several peak frequencies in LP events at Kusatsu-Shirane and Galeras volcanoes were successfully explained by those predicted from the analytical formula. In this study, we further analyzed LP events at both the volcanoes, and systematically estimated the crack model parameters at the LP sources using the analytical formula, in which we assumed misty and dusty gases at Kusatsu-Shirane and Galeras, respectively. Our estimates indicated that the crack geometry and fluid properties largely changed in our analysis period between August 1992 and January 1993 at Kusatsu-Shirane and that between 6 and 10 January 1993 at Galeras. We found that the crack volume increased with increasing gas-weight fraction at both the volcanoes. Although an increase in gas-weight fraction was indicated by Kumagai et al. (JGR, 2002) at Kusatsu-Shirane within our analysis period, our estimates indicated that the significant volume increase (from 10^{-1} m^3 to 10^3 m^3) was associated with the gas-weight fraction increase. At Galeras, we found that the crack volume systematically decreased with decreasing gas-weight fraction. An eruption occurred several days after the LP activity analyzed in this study. Our estimated trend may be caused by precursory processes leading to the magma eruption. This study demonstrates that the approach using the analytical formula is useful to constrain the source process of LP events and to diagnose the state of fluids in magma and hydrothermal systems.

Woodpecker seismicity before the flank effusive eruption at Stromboli

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Stromboli volcano in Italy is known as persistent eruptive activity (Strombolian eruptions). Its activity shifted from summit eruption to flank lava effusion in the Sciara del Fuoco on 7 August 2014. We obtain continuous seismic data during the transition from Strombolian activity to the lava effusion. In this presentation we report unusual seismic waves, that is particularly observed from 22 July until the onset of flank eruptions. The unusual waveforms were looked like repeating volcanic tremor. The tremor (single wave packet) is composed of numerous repeating pulses of 4-12Hz, that having almost same amplitude. It continues for several to ten minutes, and then disappears with some large pulses (or one large pulse). Since the characteristic waves appeared repeatedly with a short pause time of a few minutes, we call this seismic activity as “woodpecker seismicity”. Individual pulses that make up the woodpecker seismicity are very similar. They are likely to be repetitions of the same event. To investigate the waveform similarity, we extract waveform containing an arbitrary pulse as a template event and calculate coefficient of correlation with continuous data every one sample. We set lengths of template events two seconds. As a result, it was found that the emergence of a pulse can be identified based on correlation coefficient for any period of the woodpecker seismicity. Similar results were obtained by changing the template. Since the woodpecker seismicity was seen in the period preceding the flank effusive eruption, the woodpecker seismicity may have the relationship with the dyke intrusion. To check the temporal change in the hypocenter location of the woodpecker seismicity, we investigate the temporal fluctuation of time difference of correlation peaks at the two different stations (RFR, PZZ). As a result, it was found that the time difference at which the correlation coefficient reached the maximum was quite stable at both stations. From this fact, it seems that the mechanism and location have not changed. Considering the activity period, we expect that the woodpecker seismicity reflects some changes in volcanic process below the crater towards the flank eruption. We are planning to investigate the relationship between the woodpecker seismicity and the very long period (VLP) events that is constantly occurring.

Keywords: Stromboli volcano, woodpecker seismicity, transition process of volcanic eruption

Harmonic Tremors at Shinmoedake

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Background
During the 2011 eruptions, both seismic harmonic tremors (ground oscillations) and acoustic harmonic tremors (air oscillations) were observed at Shinmoedake. Here we report the behavior of the time evolution of the frequency spectrum as well as the phase portraits of the harmonic tremors, providing evidence for a non-linear plumbing system at Shinmoedake.

Data
We utilized seismographs from 4 broadband seismometers located within a radius of about 3 km around Shinmoedake. Spectrograms and power spectral density methods were used to track the changes in the peak frequencies over time. Additionally, phase portraits of displacement with respect to velocity were obtained to further illustrate the change in properties of the non-linear mechanism of the harmonic tremors.

The first seismic harmonic tremor was observed shortly after 17:00 on 2011/01/30, and similar seismic harmonic tremors occurred sporadically until 2011/01/31. The seismic harmonic tremors during this time frame had obvious but indistinct harmonic frequency peaks which fluctuated and drifted over time. The fundamental peaks were noted to fluctuate about the values of 0.9 Hz, 1.05 Hz or 1.3 Hz. The first seismic and acoustic harmonic tremor occurred at 21:49 on 2011/01/31 with a clear and distinct fundamental peak at 1.5 Hz and higher overtones starting from 3 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

On 2011/02/02, the longest seismic and acoustic harmonic tremor occurred over a time frame of 40 minutes from 20:43 to 21:23. The fundamental peak was located at around 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a double nested loop.

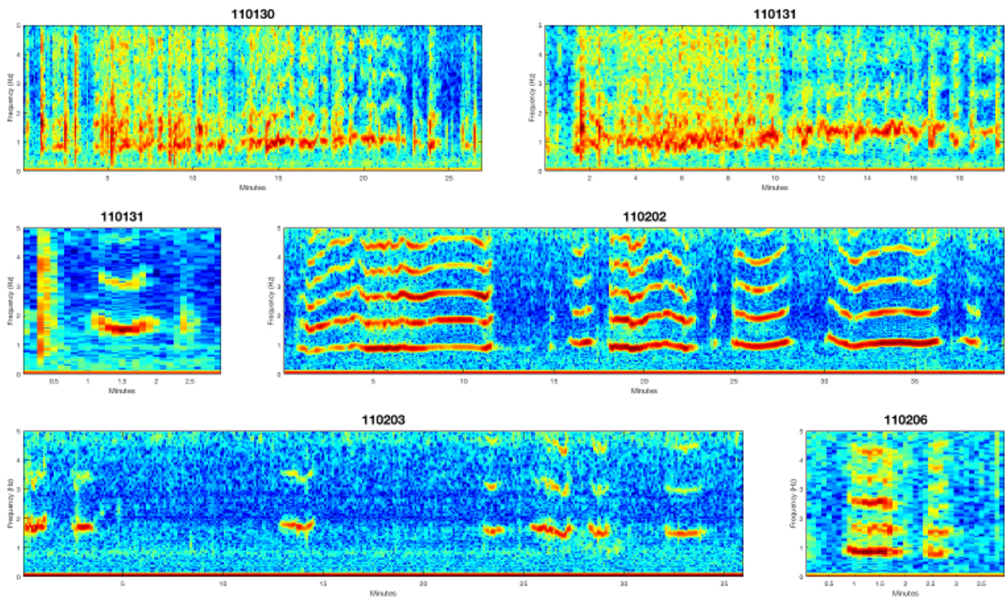
On 2011/02/03, a series of sporadic, short seismic and acoustic harmonic tremors occurred over a time frame of 35 minutes from 13:24 to 13:59. The fundamental peak was located at around 1.7 Hz with higher overtones starting from 3.4 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

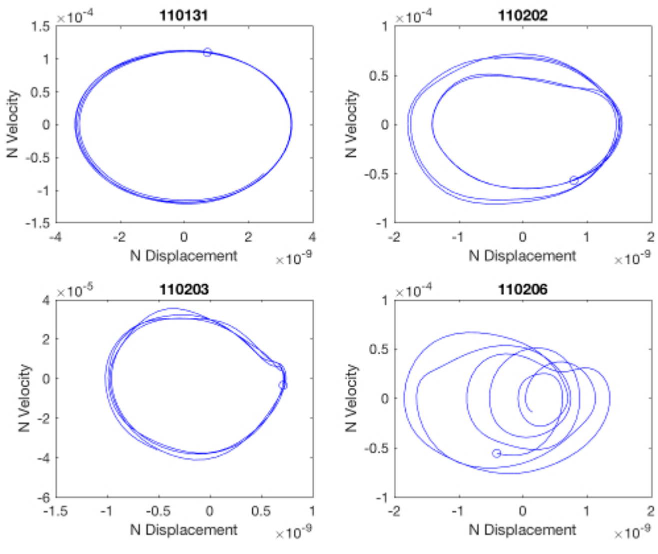
On 2011/02/06, a short seismic and acoustic harmonic tremor occurred over a time frame of just 2 minutes from 12:00. The fundamental peak was located at 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. Together with the returning of the fundamental mode to 0.9 Hz, the phase portrait of particle displacement and velocity during this time frame also shows a double nested loop.

Discussion
We interpret the jumps in frequency of the fundamental peak of the seismic acoustic harmonic tremor from 1.5 Hz to 0.9 Hz, to 1.7 Hz and back to 0.9 Hz as period doubling of a non-linear system rather than a change in physical dimensions of a resonant cavity. This period doubling is due to parameter change in the non-linear system describing the volcanic conduit, resulting in a bifurcation of the non-linear system.

We note that this observational result is supported theoretically by a lumped parameter model of non-linear excitation by fluid flow through a channel (B. R. Julian, 1994). Therefore, we treat this as evidence that the harmonic tremors at Shinmoedake are a result of non-linear fluid flow through the volcanic conduit rather than a resonance effect.

Keywords: Harmonic Tremors, Shinmoedake





Conduit opening process toward ash eruptions estimated from continuous tremor at Aso volcano: ash eruptions in May 2011 and in January 2014

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Continuous volcanic tremor at Aso volcano, has a feature to vary in amplitude with volcanic activity. Takagi et al. (2009) revealed that the source location of the continuous tremors was different between a calm and an active period. However, it has not yet been clarified about path and timing of the source migration, and relationship between the source location and occurrence of eruptions.

Ash eruptions occurred on May 15, 2011 and January 13, 2014 at Aso volcano (Japan Meteorological Agency 2011, 2014). Preceding both the eruptions, vents opened in the center of the crater bottom, 5 and 11 days before the 2011 and 2014 eruptions. Amplitude of continuous tremor increased before the opening of the vents and then decreased after the opening. While no significant change in the tremor amplitude was observed before the 2011 eruption, the amplitude gradually increased before both opening another vent and an eruption on January 13, 2014.

In this study, we estimated source location of the continuous tremor in these two eruption event periods. Then, we infer processes in a conduit system toward the eruptions. We use the vertical seismic records at five permanent stations around the active crater. The source location was estimated by a grid search technique using spatial distribution of the observed tremor amplitude (e.g. Battaglia & Aki, 2003). In this calculation, 1-D seismic velocity structure (Sudo & Kong, 2001; Tsutsui et al., 2003) and Q=40 were used. The quality factor was determined by an inversion method using t^* value (De Gori et al., 2005).

As a result of our estimation, in both the 2011 and 2014 event periods, the source locations of the continuous tremor are distributed in a cylindrical space beneath the crater. They are ranging between a depth of 400 m and the crater bottom. The distribution of the tremor source locations should indicate the shallowest pathway in the conduit system at Aso volcano. This pathway connects the crack-like conduit (Yamamoto et al., 1999) and the crater bottom distribute, through the hydrothermal fluid reservoir at a depth of 50-300 m (Kanda et al., 2008).

Another finding of the estimation is that the source location varies with changes of the activity. Before the significant increases of amplitude in 2011 and in 2014, the tremor is radiated at a 200 m depth. The source depths of the tremor with increasing amplitude before the opening the vents are different between these events, 100 m in 2011 and 200 m in 2014. This is thought to indicate processes of establishing the fluid pathway at <200 m depths, which finishes when the vent has opened with drop of amplitude. The source location has migrated to 200 m shallower region until <10 days before the ash eruptions in the both events. This source migration may be caused by processes leading the eruptions, without change of amplitude.

Based on the temporal variation in the observed amplitude and the estimated source depth of continuous tremors, we specular processes in the shallowest part of the conduit system in the 2011 and the 2014 events. Fluid supply into the pathway had increased from March 2011 and then fluid pressure in the

pathway increased. This led the pathway at a 100 m depth was widened with significant increase in tremor amplitude. Due to opening the vents, the amplitude decreased sharply on May 10. After that, the tremor source ascended. When the source reached at the crater bottom, on May 15, the ash eruption occurred. After that, the activity was once ceased by rainfall. From December 2013, the fluid supply had increased again. Then, the pathway was expanded at a 200 m depth. After the opening of the vent on January 2, 2014, the tremor source ascended to a 200 m depth. At this time, the small-scale pathway expansion also proceeded. As the shallower pathway than the depth 200 m had already been established, the source depth may jump to the near of the crater bottom. On January 13, the other vent was opened and the ash eruption occurred.

Keywords: Aso volcano, volcanic tremor, ash eruption, conduit system

Stress response of volcano-tectonic seismicity - tidal response (2)

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After the historical discovery that an abrupt increasing the seismicity was followed by the eruption at Usu volcano in 1910, volcanic seismicity is recognized to be one of the most reliable observations to predict volcanic eruptions. The seismicity prior to eruptions has many temporal patterns. In some cases, seismicity increases divergently just before the eruptions, and it has a quiescence in a few days before eruption in the other cases. The relation among the observed seismicity and physical conditions inside of volcanoes is still unsolved even the volcanic seismicity is well operationally used for hazard estimation of volcanic eruptions. Induvial earthquake may be partly controlled by accidental effects because it is caused by fracture of the rock. However, seismicity is a statistical value, and it thought to have a robust information to present the condition inside of volcanoes. We studied the relation among stress rate and seismicity change around volcanoes based on rate and state friction (RSF) law proposed by Dieterich (1994), and found out that the seismicity can be well explained by the law in the case of the stress changes by magma storage as well as ones by the great earthquake far from volcanoes. Furthermore, we found tidal response of volcanic seismicity at Izu-Oshima volcano. In this presentation, we will present the results of statistical test and tidal response changed in 2013.

Schuster’s test is well used for testing the tidal response of seismicity. It is based on the 2D random walk theory. Firstly, we use this test to demonstrate the seismicity correlate with earth and ocean tide. In this method, absolute value of stress generated by tide is not considered and we applied chi-square test as follows. Bins of tidal stress value is dived as that each bin has the same time interval of tidal stress ranges, the number of earth quakes in each bin (stress range) should be show Poisson’s distribution. Whether earthquakes occur randomly or not can be checked by chi-square test.

As mentioned before, we checked the volcanic earthquakes occurring at shallow region beneath Izu-Oshima caldera during 2004 and 2016. The null hypothesis that the earthquakes occur randomly are rejected with high confidence for the earthquakes occurring after 2013, but it cannot be rejected earthquakes before 2012. Supposing various focal mechanisms for the earthquakes, the result is not changed because the normal stress component acting on fault surface is dominant. Therefore, we tentatively use the volumetric tidal stress, that is equivalent to pressure acted on the fault planes. The earthquakes after 2013 occurred when the tidal volumetric stress is near the local maxima (extension). It means that earthquakes prefer to activate in maximum condition of the Coulomb failure function.

We will discuss that temporal change of tidal response of the seismicity. At very active volcanic zone of ocean bottom in West Pacific Rise, seismicity increased when tidal volumetric stress becomes local maxima distinctly (Stroup at al., 2007). In fact, as decreasing effective normal stress acting on the fault plane becomes low, the tidal response of seismicity becomes distinct and earthquakes prefer to occur in maximum extensional tidal stress. We have found out that the volcanic earthquakes at shallow occurring beneath Izu Oshima caldera, are affected by stress changes generated by magma storage in the reservoir located at the depth of 5km. And the seismicity after 2011 was greater than the expected value calculated using RSF model. The both fact show that the effective normal stresses at fault planes decreased in 2011 or 2013, and kept low value until the present. One of the most feasible reasons of the low effective normal stress is increasing pore pressure beneath the hypocenter zone located just above estimated pressure source of magma reservoir.

Izu Oshima volcano repeats eruptions every 30-40 years, and latest eruption occurred in 1986. It passed over 30 years. The above observations probably caused by uprising of volatile component from magma

reservoir, and it makes the pore pressure at the hypocenter zone increases, and decrease effective normal stress on the fault planes of the volcanic earthquakes after 2011 or 2013. This is one of the possible precursory phenomena of next volcanic eruption. And we would like to exaggerate the volcanic seismicity is very sensitive to stress in this case.

Keywords: volcano-tectonic earthquakes , seismicity, tidal response, active volcano, volatile component

Brief overview of landing survey and seisimic observation at Nishinoshima

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A new volcanic islet had been growing up with lava effusion and Strombolian acitivities at Nishinosima, Izu-Bonin arc from November 2013 to November 2015. The morophological evolution of Nishinoshima had been revealed based on airbone observtions and satellite images. The eruption activity has been monitored continuously using ocean bottom seismograph observation; the number of eruptions had registered a decline gradually, the eruption having stoped by the end of November 2015. After the volcanic activity falling to a low level, we had promoted a research survey of volcanology and bionomy at Nishinoshima from October 16th to 25th, 2016, using an academic investigation ship “Shinsei-maru” managed by AORI, University of Tokyo. The investigation item of the landing team were geological survey, installation of seismic station, and survey on nidification of seabirds. OBSs and OBEMs had been installed around Nishinoshima, pre-installed OBSs having recoverd. A monitoring system of remote volcanic island using WaveGlider was operated around Nishinoshima on a trial basis. An analysis of whole rock chemical composition of volcanic products in 2013-2015 eruption reveals that all samples are composed of andesite with SiO_2 content of 59.5-59.9wt%, falling on middle content between the eruption products in 1973-1974 eruption and the laval of the old islet. The telemetric seismic monitoring system in Nishinoshima is on couse to operate; the seismic data occasionally include long-lasting high-frequency tremors which seem to be related with some sort of Nishinoshima activity. We will make clear the growing process of volcanic islet together with geological and geophysical knowledges based on futher analyses of volcanic products and those of OBS and OBEM data which will be recovered on June 2017.

Keywords: Nishinoshima, volcanic islet, eruption

Geology and eruptive process of new Nishinoshima, Ogasawara, Japan, revealed from first landing and survey of eruptive products

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The island-forming eruption at Nishinoshima volcano, Ogasawara Islands, Japan, began its activity in November 2013 and ended in late 2015. During the KS-16-16 cruise in October 2016, we landed on Nishinoshima for the first time since the beginning of the eruption, and studied geological features of the new island. We approached and landed the western coast of the island where the pre-existed island remains partially. Along the gravelly coast, we observed many lava lobes that were emplaced during the different eruption periods between early 2014 and mid 2015. The periods of lava emplacement were determined based on aerial photos and satellite images. The front of lava lobe (a few to >10 m thick) is generally eroded by wave action and exposed its interior. The lava lobes consist of a black or dark gray, glassy clinker part and a massive inner part, some of which are highly fractured, vesiculated, and/or oxidized. Rubbly lava surface was commonly observed. The top of pre-existed island is covered by ash and scoria fallouts with thickness of ~10 cm or more that were caused by Strombolian activities in early periods and ballistic ejecta (a few tens cm) from the latest Vulcanian activity in November 2015. One of lava lobes in the northern area has a chilled margin that is characterized by a few-cm-thick glassy rim with many fine cracks developed perpendicular to the lava surface. From boats, we also observed clefts along the axial crest of lobes, exposing the interior of massive part of lava flows. They are thought to be products from lava inflation driven by an increase of internal pressure by successive injection of new lava into the lobes during lava emplacement as proposed by Maeno et al. (2016). We collected samples from lava lobes and fallout deposits for petrologial analyses. The analyses were carried out together with other rock samples collected by different surveys at Nishinoshima (by ERI using an unmanned helicopter in June 2016 and by Japan Coast Guard in October 2016). The 2013–2015 lava flows were andesite with <10 vol.% of phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and titanomagnetie. The whole-rock composition is 59.5–59.9 wt.% in SiO_2, analyzed by an XRF at ERI. The petrological features of the 2013–2015 lava flows are similar to those of products from the past eruptions at Nishinoshima (e.g., Umino and Nakano, 2007); however, the whole-rock compositions are clearly distinguished from the 1973–1974 products and the pre-1702 products (older lava), and lies on the narrow range between these two products. Moreover, it seems that the SiO_2 (MgO) contents of lava flows slightly decreased (increased) with time, indicating more differentiated magma was erupted in early stage, although those of fallout deposits doesn’t show such specific chemical trend through the eruption. Although more geological and petrological analyses are needed to explain the origin of chemical variations in products, our findings during surveys at new Nishinoshima offer important insights into understanding the eruption process of this volcano.

Keywords: Nishinoshima, lava, lava lobe, fallout deposit

Long-term seismic monitoring around Nishinoshima, Izu-Ogasawara by using ocean bottom seismometers

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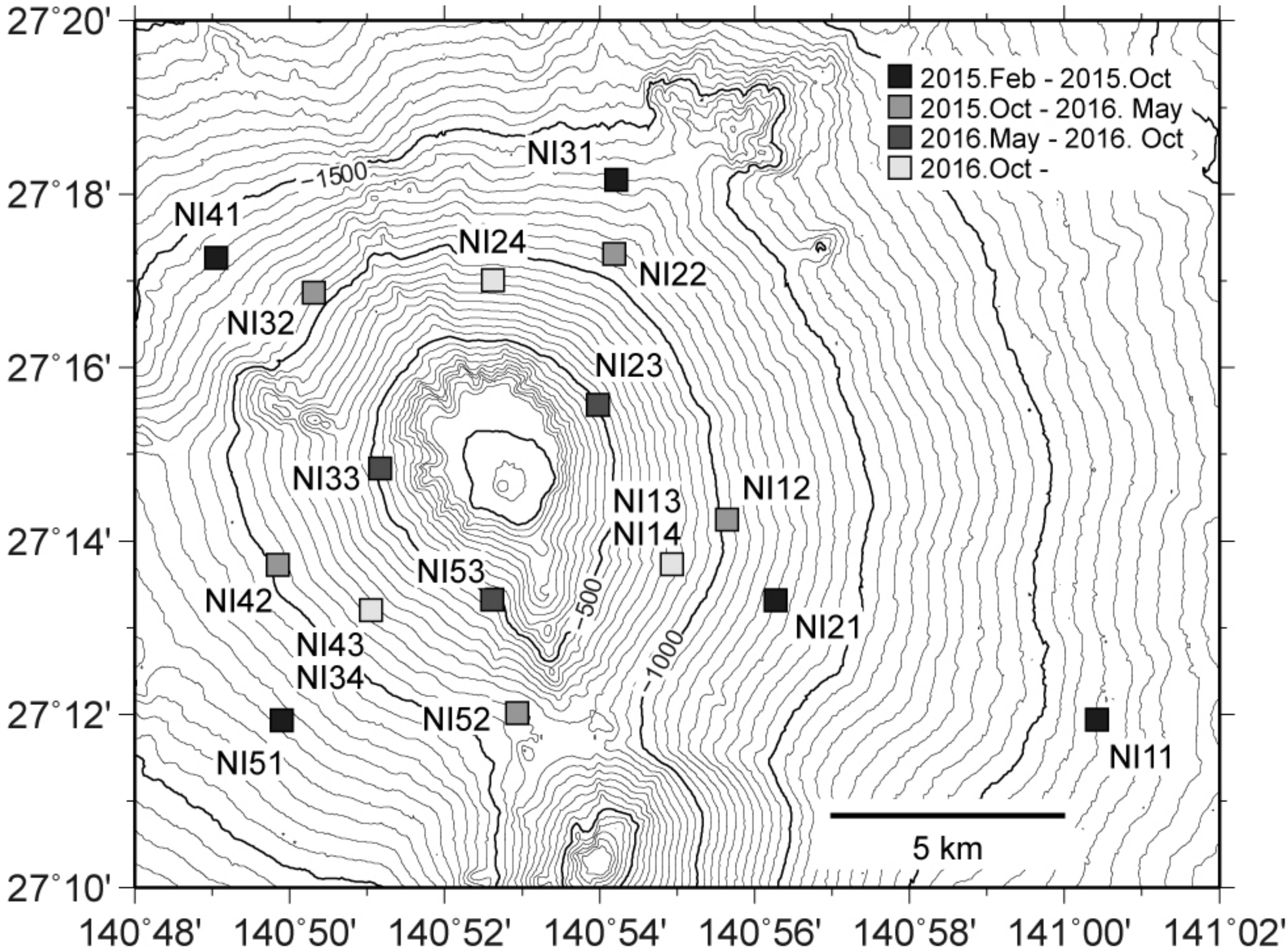
Nishinoshima in Izu-Ogasawara erupted in 1973 and island was newly created. In November 2013, eruption of Nishinoshima volcano was confirmed again and a size of the island increased. It is difficult to make continuous observation on an uninhabited island such as Nishinoshima. Therefore we started seismic observation using Long-Term Ocean Bottom Seismometers (LT-OBSs) from February 2015 when the eruption occurred continuously. Our LT-OBS equips three-component 1Hz seismometer, and has a recording period of one year. The first deployment was carried out by the R/V Kairei, JAMSTEC. We deployed 4 LT-OBSs at a distance of about 8 km from a central crater of Nishinoshima where water depths are about 1,400 m and a LT-OBS at a distance of about 13 km. In October 2015, the deployed LT-OBSs were recovered by the R/V Keifu-maru, JMA, and 5 LT-OBSs were installed to continue the observation. Five LT-OBSs were had a distance of 5 km from the crater and water depth is about 1,000 m. In May 2016, the the R/V Shoyo, JCG retrieved the 5 LT-OBSs and deployed 5 LT-OBSs at positions closer to the island. In October 2016, 5 LT-OBSs were recovered by the R/V Shinsei-maru, JAMSTEC and 3 LT-OBSs were installed again to continue the observation. We will report temporal variation of activities of Nishinoshima volcano from the records of LT-OBSs.
LT-OBSs frequently recorded characteristic events from a start of the observation. The first part of the events has high frequency of a few Hz and large amplitude waves with a period of a few seconds follows. This characteristic waves have good S/N ratio at frequencies from 4 Hz to 8 Hz. Duration of the events are less than 1 minutes (usually 20-30 s) at frequency band of 4-8 Hz. Therefore we applied the band pass filter of 4-8 Hz to all records from OBSs for analyses. For the first period, four LT-OBSs had the same distance from the crater and the waves arrived at the same time with the same amplitude. We located hypocenters of these events using the first arrival times, and epicenters were located close to the crater. In February 2015, infrasound and picture observations were performed on the R/V Kairei, and infrasound was observed during release of plume from the crater. Compared the events recorded by a LT-OBS deployed during the infrasound observation with infrasound data (1-7 Hz) and picture of the crater, the events on the LT-OBS records seem to correlate with release of plumes.
We estimated the number of the events which are related to plume release by using the STA/LTA method. The method is applied to the records of more than three LT-OBSs. First, a bandpass filter of 4-8 Hz was applied to all the records and we adopted parameters of the STA/LTA method as follows, STA window: 2 s, LTA window: 40 s, STA/LTA ratio: 1.5, duration of trigger: 3 s, time for re-trigger: 4 s. The events are recognized by more than three triggers at the same time, and continuous trigger is interpreted as one event. We detected 363,367 events from 2015 February 28 10:00 to 2015 October 3 13:00 (the first observation period). In the second observation period (from 2015 October 4 01:00 to 2016 May 5 08:00), 27,544 events were picked up. For the second period, we changed the parameter of STA/LTA ratio to 2.0 due to a change of configuration of the LT-OBS network. From the start of the OBS observation (2015 February) to June, the number of detected events is constant of approximately 1,800 per day. From middle of July 2015, the detected number rapidly decreased, and duration time of the events became longer. In the end of October 2015, the number was reduced to less than 300 per day.

Although the number temporarily increased at the beginning of November, the number of the detected events reached less than 100 per day after the end of November. It is estimated that the surface activity of Nishinoshima volcano declined from the end of July 2015, and there was little activity from the middle of November 2015 to at least May 2016.

Keywords: Nishinoshima volcano, Long-term ocean bottom seismometer, Temporal variation of activity of Nishinoshima volcano



First operation of the remote-island volcano monitoring system around Nishinoshima

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We develop a remote island volcano monitoring system by using the Wave Glider (WG), which monitor the volcanic activity of remote islands while autonomously navigating around the island far from the land, and transmit the information to the land station by satellite communication. During the KS-16-16 cruise of R/V Shinsei-maru in October, 2016, we deployed the newly developed system into the Nishinoshima sea area, and the short-term operation was performed. The monitoring system is equipped with 1) the 4 time-lapse cameras for taking pictures of volcanoes, 2) the 2 microphones for infrasound observation, 3) the hydrophone installed at 6 m below sea surface for earthquake observation, and 4) the wave meter utilizing GPS Doppler velocity measurement for detecting tsunami generation by the land slides of the volcanic body. Sound wave signals by the microphones and hydrophone, and the wave meter records are transmitted by the satellite communications to the land station. For the navigation and control of the WG, other satellite system is employed, and the navigation data set (location, speed, current speed and direction), and the weather data set (temperature, pressure, wind speed and direction) are transmitted independently to the land.

The system is launched about 1km west to the Nishinoshima at 0935 on October 20, 2016. After the launch, the system start navigation autonomously along the track of circling the island with a radius of about 5 km. After one circle of the track, the system was recovered on board at the north-west to the island at 1345 on October 21, 2016.The average amplitude of the observed sea waves was about 50 cm, and the period was around 10 sec. The water speed of WG was in the range of 1.2 - 0.9 knots. On the other hand, the ground speed observed by the GPS Doppler measurement had the mean speed of 0.5 knots, and it took more than 30 hours for travelling the distance of 30 km along the circular track.

The wave meter measures and records the heave and the three components of speed with 10 Hz sampling rate. In normal mode, data communications via satellite to the land station transmit 1 Hz sampling data sets (about 600 byte) in every minute. In emergency mode, 10 Hz sampling data sets (about 4900 bytes) are transmitted in every minute. In the present experiment, the normal mode transmission of the date sets were performed without an error, and the switch between two modes was successful. Heave and speed measurements of the wave meter are performed with the precisions cited in the specification (5 cm in heave, and 0.05 m/s in speed). The frequency spectrum of the heave seems closely resemble that of the wind generated waves in typical coastal area with a central frequency of 0.1 Hz.

Sound waves observed by the microphones and hydrophone were recorded by the data logger at sampling speed of 200Hz. Examination of the data sets indicates that the waveform of the microphones are highly correlated with that of the waves, suggesting that the microphone records the pressure change by the up-down movement of the float of WG. Since the Nishinoshima volcano did not erupt at that time, the high frequency signals more than 2Hz corresponding to the infrasound waves were not observed in the microphones. On the other hand, many line spectra are seen in the higher frequency side (>10 Hz) of the hydrophone spectram. During KR-15-17 cruise of R/V Kairei in Feburuary 2015, we made hydrophone measurement by lowering the hydrophone from the ship to the water depth of 10m, while the Nishinoshima volcano was highly active and continuous eruptions occur. The spectrum of the hydrophone records show many line spectra higher than 10Hz, which corresponds to BH-type earthquakes. Considering the observation in 2015, it seems that the activity of the deep part of the

Nishinoshima volcano does exist even now.

Keywords: Nishinoshima, Remote island, Volcanic activity monitoring

The October 7-8, 2016 eruptions of Nakadake crater, Aso Volcano, Japan and their deposits

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The Nakadake first crater of Aso Volcano (SW Japan) erupted at 21:52 on October 7, 2016, and the first eruption was followed by an explosive activity at 01:46 on October 8. The October 8 explosive eruption produced ash plumes rising to altitude of 11000 m asl that drifted E-ESE. The ash-fall deposit was dispersed over an area extending 350 km northeast of the volcano. We performed fieldwork for observing and sampling of the related deposits in the proximal and distal areas immediately after the eruption.
The October 7-8 eruptions emplaced a large amount of poorly-sorted deposits containing abundant block-size clasts around the Nakadake first crater. Although the total thickness of deposits associated with the October 7-8 eruptions at the southwestern crater rim was about 1 m, the maximum thickness was likely to reach 1.5-2 m because some shelters (2-2.5 m high) were almost buried by the deposits. A large number of ballistic clasts of a few ten centimeter across was scattered around the crater, and the largest clast with a size of 3×2.2×1.5 m existed at the southwestern crater rim. Since several lobate deposits of 0.5-1 m high and a few meter wide occurred along gullies in the proximal area, most of proximal deposits were interpreted to be derived from pyroclastic density currents (PDCs). Based on a helicopter inspection immediately after the eruption, the mass of the PDC deposits was roughly estimated at 4.5×10^5 tons.
The October 8 ash-fall deposit was clearly distributed about 70 km to the northeast of the source crater. Lapilli-size clasts were dispersed to areas up to about 30 km east-northeast of the crater. The dispersal axis of the maximum size of clasts was slightly more easterly than that of thickness. The mass of the ash-fall deposit (including lapilli-size clasts) was calculated at about 1.8×10^5 tons. Adding the mass of the PDC deposits, the total eruptive mass of the October 7-8, 2016 event was $6\text{-}6.5\times10^5$ tons.
The polarizing microscope observations revealed that a sample of the October 8 ash-fall deposit consisted of glass shards (20 %), crystal (20 %) and lithic (60 %) grains. Most glass shards were unaltered poorly crystallized pale brown glasses and highly-crystallized black glasses, which probably represented juvenile magma. Results of EPMA analysis indicate that chemical composition of glass shards included in the October 8 ash-fall deposit was similar to those of glasses in the 1979, 1989-1990 and November 2014-September 2015 ash.
The October 7-8, 2016 eruptions of Nakadake first crater were characterized by explosive phenomena including ballistic projectiles and pyroclastic density currents, and were similar in deposit volume to eruptions on September 6, 1979 and April 20, 1990.

Keywords: Aso Volcano, Nakadake crater, phreatomagmatic eruption, ballistic clast, pyroclastic density current

2015-16 years activity of Niigata-Yakeyama volcano; ash emission eruptions and syneruptive-spouted type lahar generated in 2016 year eruption.

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Niigata-Yakeyama Volcano, Niigata prefecture in central-Japan, consists of lava dome and pyroclastic flow and is young active volcano. Recently, in this volcano, phreatic-eruptions occurred in 1949 and 1974; small-scale eruptions (ash emissions) occurred in 1983-84, 1987, 1989, 1997-1998 and 2016. We report of the sequence of 2015-16 years activity of Niigata-Yakeyama Volcano, based on the analysis of tephra and observation from the ground and aerial. From the end of August 2015 to the fall of 2016, the fumarolic activity of Niigata -Yakeyama Volcano was active. In 2016, Niigata-Yakeyama Volcano emitted volcanic ash 8 times (6 times before April 15, once in May and July) and syneruptive-spouted type lahar 6 times (May 1-8 and 20, June 3-4 and 26, July 2 and 19). Along with these ash emissions, release of ejected rock fragments and high temperature matters has not been observed. The emitted volcanic ash was found to be composed of altered volcanic fragments, flesh plagioclases, pyroxenes and roundness volcanic rocks fragment. However, the absence of juvenile material in the eruptive products indicates that the eruption was phreatic. The estimated total discharged mass was less than 10^6kg. From these characteristics, it is estimated that the eruptions of 2016 is phreatic eruptions that occurred when the surrounding fine grains were blown off by activation of fumaroles. However, the eruption of warm or muddy water from the volcanic body (syneruptive-spouted type lahar) is a characteristic activity of 2016 eruption.

Keywords: active volcano, Niigata Prefecture , eruption, tephra, volcanic ash, syneruptive-spouted type lahar

Fumarole activity at the southwest rim of Ioyama crater in the Ebinokogen

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A new fumarole that appeared on the southwest rim of the Ioyama crater in the Ebinokogen volcanic area on 14 December 2015 spread rapidly in January–February 2016. The occurrence of frequent volcanic earthquakes in a single day, on 28 February 2016, led the Japan Meteorological Agency (JMA) to issue a level-2 volcanic alert (JMA website[1]). Although the volcanic alert level was downgraded to level 1 in March, a gradual spread of the fumarole area was observed in April and August 2016. The present study measured the high-temperature area by employing easy triangulation using two tape measures; however, this method was difficult to apply to the expanding area in late August. Therefore, air photographic survey by drone was used in high-temperature areas.
Prior to the drone observation, we set markers showing 50˚C on 20, 22, 25, and 27 November 2016. Just before the day of observation on 9 December, the 50˚C points were modified. Aerial footage was recorded by the Phantom 3 drone on 10 and 11 December which was then converted to orthophotographic images. Markers with diameters of 18 cm were more clearly observed about tens of meters height above ground level and were plotted on the orthophotographic images, and the areas of 50˚C were then measured. The high-temperature area was 3500 m^2 on 10 December, which indicates an expansion of the 2200 m^2 high-temperature area measured on 20 August.
Very high concentrations of H_2S volcanic gas were observed in the middle of October (Miyazaki prefecture website[2]). White turbidity in the river caused by sulphur from Ioyama was found on 29 October by a member of the Kirishima Nature guide club. It was assumed that expansion of the high-temperature area was occurring at that time. On 12 December 12, frequent volcanic earthquakes occurred (JMA website[1]). The expansion of the high-temperature area from December 2015 to February 2016 and from October 2016 to the present indicates the occurrence of strong underground volcanic activity.

1 http://www.data.jma.go.jp/svd/vois/data/tokyo/volcano.html
2 http://www.pref.miyazaki.lg.jp/kiki-kikikanri/kurashi/bosai/iouyamagasu20160226.html
Observation members of Kirisima nature guide club: Toshio Furuzuno, Kentaro Haraguchi, Takeji, Nagatomo, Takamichi Higashi, Hideaki Yoshinaga, Midori Baba, Masashi Takada, Yukikazu Matsumura.

Keywords: Kirishima volcanoes, Ioyama, Fumarole

Time variation in the volcanic gas at Hakone volcano with the interpretation

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Introduction

At Mt Hakone, the swarm of volcanic earthquakes happed in June to Oct 2001 with the pressure increase of steam discharged from boreholes drilled in Owakukdani geothermal area. A similar phenomenon happened in the end of April 2015. During the occurrence of earthquake swarm in 2015, a small steam eruption happed in Owakudani geothermal area. We should expect another earthquake swarm and eruption at Mt Hakone in future. In general, the chemical composition and isotope ratios of volcanic gas change along the progress of volcanic activity. The prediction of earthquake swarm based on the volcanic gas contributes the mitigation of volcanic hazard at Mt Hakone. In this study, we report the chemical composition and isotope ratios of fumarolic gas sampled at Mt. Hakone since May 2013, and try to interpret the time variation.

Fumarolic gas

We have sampled two fumarolic gas at fixed location with the frequency of once per month. One point of sampling is located within Owakudani geothermal area. Another point of sampling is located in Kamiyuba geothermal area, 500m far from Owakudani gothermal area in north direction.

Result and discussion

A significant increase in CO2/H2O ratio happed in May 2015, at the both fumarolic gas, which synchronized with the start of volcanic earthquake swarm. The increase could be brought by the development of sealing zone surrounding a degassing magma. The sealing of degassing magma increases the pressure of magma and also increases the CO2/H2O ratio of gas equilibrated with magma. A magmatic fluid with high CO2/H2O ratio would be injected to the shallow hydrothermal system after the break of developed sealing zone. The injection produced the earthquake swarm, the pressure increase in steam from bore holes, and the increase in CO2/H2O ratio of fumarolic gas.
Before the earthquake swarm in April 2015, a significant increase in N2/He ratio was observed. The increase started in Feb 2015, being kept until the start of earthquake swarm. The change can be also explained by the magma sealing model. Before the break of sealing zone, the supply of magmatic fluid to the shallow hydrothermal system had been suppressed. The fluid pressure in the hydrothermal system was lowered by the suppression, which induced the invasion of atmospheric air from surface. The contaminated air was involved in the fumarolic gas, which caused the increase in N2/He ratio.
The fumarolic gas from Mt Hakone contains H2 gas and H2O vapor. An apparent equilibrium temperature (AET) can be calculated by use of D/H of H2O and H2. The AET was stable with average around 100C before Aug 2014 for both fumarolic gases, and dropped to 70C after Sep 2014. The drop continues about 2 months. During the occurrence of volcanic earthquake in 2015, AET increase to 130C in average. After the earthquake, AET was stabilized to 110C in average. The drop of AET may be a precursor for the earthquake swarm in 2015.

Keywords: Volcanic gas, Mt Hakone, Eruption

Thermal activities around Shrirane pyroclastic cone, Kusatsu-Shirane volcano

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Phreatic eruptions have repeatedly occurred at Shirane pyroclastic cone, Kusatsu-Shirane volcano, over the last 130 years. Shirane pyroclastic cone exhibits thermal features such as hot crater lakes and steaming grounds. The most active hot crater lake, Yugama, contains extremely low pH water resulting from subaqueous fumarolic activities. On the northern slope of Shirane pyroclastic cone, vigorous steaming grounds emit volcanic gas which is mainly composed by H_2O, CO_2 and H_2S with a temperature of around 100 degree Celsius. MT surveys have revealed that a low resistive layer exists beneath Shirane pyroclastic cone. The layer may act as an impermeable layer enabling to store volcanic fluids supplied from depth. According to precise geophysical observations, hypocenters of micro earthquakes are located around undersurface of the impermeable layer. Sources of Long-period events, ground deformations and magnetizations are determined around the impermeable layer, meaning hydrothermal reservoir exists under the impermeable layer.

Thermal manifestations of Shirane pyroclastic cone are likely caused by fluid leakages from the reservoir; I believe monitoring of thermal activities are useful to evaluate activities of the hydrothermal reservoir. To estimate heat flux from vigorous steaming grounds, precise measurements of spacial distributions of ground surface temperatures are necessary. Using an infrared thermography, aerial infrared surveys have been repeatedly carried out since 2012. Most of these observation were done in the nighttime because even slight anomalies in ground surface temperature can be detected.

Intense earthquake swarms have occurred at shallow depth of the Shirane pyroclastic cone since March 2014, accompanied by ground deformations, changes in geomagnetic field and chemical concentrations of volcanic gas. A location of the pressure source is determined by network of our tilt meters at 550 m depth from Yugama crater lake, corresponding to the location of hydrothermal reservoir. We consider that increases in heat-discharge rates observed in 2015 and 2016 mean fluid leakages from the reservoir.

On the southeast slope of Shirane pyroclastic cone, no anomalies of ground surface temperatures were detected by the aerial infrared surveys while phreatic explosions occurred between 1927 and 1942 in this region. Fumaroles with a temperature of 148 degree Celsius emitted volcanic gas containing SO_2 and HCl in the early 1960s in the region. We believe that such intensive explosions developed permeable zone in the cap rock layer beneath the Shirane pyroclastic cone, as a result, high temperature volcanic gas emitted from here exclusively.

I find a stream which hot water springs out from the streambed. We collect water sample and measure flow rate systematically in order to estimate temperature, enthalpy, pH, concentrations of anions and stable isotope rates of hydrogen, oxygen and sulfur. Furthermore, Volcanic Fluid Research Center (VFRC), Tokyo Institute of Technology, has dug a monitoring well at 700 m east from the center of Yugama crater lake in 2016. At the depth of 50 m, VFRC finds a hot water vein with a temperature of 31 degree Celsius. Inserting a slender bottle to the well VFRC can easily collect water sample from 50 m depth. In addition to the thermometer installed in 2016, VFRC plans to install sensors of water level, pH and electrical conductivity in the well. These physical and chemical features of water in the southeast slope of Shirane pyroclastic cone enable us to discuss signs of magmatic high temperature volcanic gas leakage from the hydrothermal reservoir.

Keywords: Kusatsu-Shirane Volcano, Hydrothermal system, Fumaroles, Monitoring well, Infrared thermography

Magmatic hydrothermal system inferred from the resistivity structure of Kusatsu-Shirane Volcano

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Kusatsu-Shirane volcano consists of two main pyroclastic cones. One is Mt. Shirane located in the northern part of summit area, which has three active crater lakes. Various geochemical and geophysical researches have been conducted and several models of the subsurface structure and the hydrothermal system have been proposed. The other is Mt. Motoshirane located about 2 km south of Mt. Shirane. In this area, no volcanic activity is observed today, and therefore studies targeted for this cone have not been conducted other than several geological studies. Two major hot springs of the volcano, Kusatsu and Bandaiko hot springs which are characterized by high-temperature and high-discharge-rate, occur in the east flank of Mt. Motoshirane. The recent geological study revealed that the last magmatic eruption had occurred from Mt. Motoshirane about 1500 years ago.

We conducted a magnetotelluric (MT) study on the subsurface structure of Mt. Motoshirane in this study. The MT method is a kind of electromagnetic method to infer the subsurface structure and sensitive to conductive materials such as melt and hydrothermal fluids. The objective of this study is to clarify the whole image of magma-hydrothermal system of Kusatsu-Shirane volcano. The final three-dimensional (3-D) resistivity model revealed the presence of a conductor (henceforth we call it C2) beneath the summit area extending from Mt. Shirane to Mt. Motoshirane. Since the horizontal extent of this conductor covered two clusters of hypocenter distribution which are located within each pyroclastic cone, the conductor was interpreted as a hydrothermal fluid reservoir providing fluids to the shallow terrain and causing volcanic earthquakes. From the result of the 3-D resistivity structure indicating no conductor which is considered to preserve such volcanic fluids in the region between the hot springs of the east flank and C2, we consider that the conductor C2 is a source of the heat and fluid of Bandaiko and Kusatsu hot springs, and propose the following model of a hydrothermal system of the volcano.

The region beneath the C2, a heat source is located and provides the heat and fluids to C2. The heated fluids in C2 ascend to the summit area, causing volcanic earthquakes. A part of the heated fluids ascends to the east flank of Mt. Motoshirane, through fractures of the Kusatsu fault, and forms a hydrothermally altered zone and fumarolic zones such as the Sessho fumarolic area. Mixture of ground water and the fluids from C2 flows down to the east flank of the volcano and is discharged as Bandaiko and Kusatsu hot springs.

In a deep part of the volcano, no conspicuous feature indicating the existence of magma was found in the final resistivity model. However, it does not necessarily mean that there is no magma chamber beneath the region. Additional observations and/or simulations are required in order to constrain the location of magma, which should be carried out in the future.

Keywords: Kusatsu-Shirane volcano, Mt. Motoshirane, resistivity structure, hydrothermal system, magma reservoir

Three-dimensional resistivity structure around the lava dome of Chausu-dake volcano inferred from the AMT measurements

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Chausu-dake volcano is located in the northern part of Tochigi prefecture, and started volcanic activity about 16000 years ago. Six large-scale eruptive activities including the magmatic eruptions and many phreatic explosions were reported. The last large-scale activity occurred during 1408-1410 and formed a present lava dome in the summit area. After that, several phreatic explosions occurred repeatedly and formed two craters on the northwestern side and western side of the lava dome on July 1st, 1881. Recently, phreatic explosions occurred in these craters in 1953, 1960, and 1963, and fumarolic activities are observed there today.

According to the observation by the Japan Meteorological Agency (2015), the fumarolic temperature decreased gradually after the phreatic eruption of 1963 and is kept at about 100℃ recently. Volcanic earthquakes within the edifice are hardly observed and the plume height is low. It seems that volcanic activity is quiet. It is important to know the subsurface structure of the volcano which is in a decreasing volcanic activity. This is because the inner structure of a quiet volcano provides the basic information to know the present state of volcanoes in the increasing activity. Therefore, we investigated the resistivity structure around the lava dome of Chausu-dake volcano using audio-frequency magnetotelluric (AMT) method.

An AMT measurement was already conducted around Chausu-dake volcano by Aizawa et al. (2009) and two-dimensional resistivity structure was inferred. The result shows that the volcano constitutes a thin resistive layer underlying a thick conductive layer. The conductive layer was considered to be composed of the upper layer which is rich in conductive clay minerals and therefore has low permeability and the lower layer containing hydrothermal fluids. The altered layer was considered to act as both the base for meteoric groundwater flows and the cap for hydrothermal fluids. However, the model of Aizawa et al. (2009) was obtained from a two-dimensional inversion using only the TM-mode data, although the data showed three-dimensional (3-D) features. In addition, the AMT data was measured along a mountain trail south of the lava dome, so a detailed subsurface structure of the lava dome is still unknown..

In this study, we carried out an AMT survey in the whole area of the lava dome in 2016 to clarify more detailed structure beneath the lava dome of Chausu-dake volcano. In the presentation, we are going to report a three dimensional resistivity structure model inferred from the AMT data observed by this study and of Aizawa et al. (2009), in which the topography is incorporated.

Keywords: Nasu volcano group, Chausu-dake volcano, AMT, lava dome, resistivity structure

Geoelectromagnetic investigations of Yake-dake volcano - wideband magnetotelluric measurements and magnetic survey -

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In order to delineate subsurface structures as basic information for monitoring Yake-dake volcano, we carried out wideband magnetotelluric (MT) measurements. For clarifying electrical properties, we totally obtained electromagnetic data at 11 sites along a north-south profile and estimated MT responses by using the remote reference technique. Obtained preliminary result of a two-dimensional inversion reveals a cap-like conductor just beneath the latest phreatic eruption. Additionally, we performed ground magnetic survey along a north-south profile crossing the summit of Yake-dake volcano. To simulate obtained magnetic anomaly, a zone of low magnetization is required at the same location as the cap-like conductor.

Keywords: Yake-dake volcano, magnetotellurics, ground magnetic survey

Vertical ground deformation after the August 2015 dike intrusion event at Sakurajima volcano measured by leveling survey

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We conducted the precise leveling survey in Sakurajima volcano in November 2016. The main purpose of the survey is to reveal the vertical ground deformation after the dike intrusion event occurred on August 15, 2015. The leveling routes measured in this survey are about 56 km long in total, including Sakurajima coast route, Sakurajima western flank route and Sakurajima northern flank route. These leveling routes were measured during the period from November 1 to 24. Mean square errors of the conducted survey were achieved with a good accuracy as the range from ±0.14 to ±0.26 mm/km.
From the measured data, we calculate the relative height of each bench mark referred to the reference bench mark BM.S.17 which is located at the western coast of Sakurajima. The calculated relative heights of the bench marks are then compared with those of the previous survey conducted in August-September 2015 (Yamamoto et al., 2016), resulting in the relative vertical displacements of the bench marks during the period from August-September 2015 to November 2016.
The resultant displacements indicate the remarkable ground uplift at bench marks around the northern part of Sakurajima. The amount of the maximum uplift is as much as about 20.5 mm referred to BM.S.17. On the other hand, the ground subsidence is detected around Arimura (southern part of Sakurajima).
From the preliminary analysis based on Mogi’ s model, the inflation and deflation sources are located beneath the northern part of Sakurajima and beneath the east of Showa crater, respectively. The inflation source represents the magma accumulation around the location, while the deflation source is supposed to reflect the pressure decrease related to the previously intruded dike.

Keywords: Sakurajima volcano, precise leveling survey, vertical ground deformation

The viscoelastic responsive interpretation by ground deformation observations of magma intrusion event into Sakurajima volcano on August, 2015 that contained pre- and after- activities.

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Introduction

Failed eruption, Magma intrusion event into Sakurajima volcano, occurred in August, 2015. From about 7:05 of 15th, VT earthquake was observed, and ground deformation was observed by tiltmeter and extensometer from about 8:00. Following, VT-seismicity became active, and the ground deformation rates increased from 10:27. Low frequency earthquake, large amplitude, was observed on 11:32 and 11:43. Subsequent VT-seismicity and ground deformation gradually became low-active. Ground deformation, like a after slip deformation, continued until about 17th(named intrusion process). By multi parameter ground deformation obsevation (tiltmeter,extensometer,GNSS,InSAR), the intrusion process is interpreted as WNW-ESE tensile crack, tips at 1km b.s.l, and volume change is about $10^6 m^3$ (e.g. Hotta et al., 2016 and Morishita et al., 2016). In followed period (named relaxation process), deformation polarity turned over. At the observation point near intrusion source (e.g. arimura), the deformation was exponentially, as viscoelastic stress relaxation process. On the other hand, at remote point, it seems to be also affected by other factor. In this study, We investigated the spacial-temporal pattern of intrusion process and relaxation process in detail.

Data and Methods

We analyzed tilt and strain data observed at the sites on Sakurajima, operated by SVO and JMA. We divided a intrusion process into 4 stages and defined 5 stage (4stage and relaxation process). (A: 08:00-10:27 B: 10:27-11:15 C: 11:15-11:45 D: 11:45, 15th-18:00, 17th E: 18:00, 17th-)
For each stage, We estimated source by dislocation model (Okada, 1992). Observation data at each sites are coordinate conversion to the directions of calculation value by best fit model. We analyzed the normalized conversion data, temporal response series.

Results

For the tilt data at Arimura, We assumed delay time. Delay time is response factor, assumed Kelvin-Voight medium, when it give step function at the beginning of each stage. The delay time is approximately 50 minutes in stage A - C, but is approximately 360 minutes in stage D. In stage E, relaxation time is approximately 90days (1.3×10^5min) and approximately 40% returned.
It was accepted that delay time is correlation with the distance from the source by relative impulse response (other site to Arimura). In addition, the response at sites in the tensile direction are more rapid than that in the strike direction. At the tensile direction, relative delay time increased from 8:00 to 11:45 on 15th, in following Stage D, it gradually decrease. For Stage E, relative relaxation time have the same correlation. This means inverse correlation with the ratio of deformation in StageE to in StageA-D.

Discussions in meeting

The decrease delay in stage D is interpret as stress relaxation of local stress concentration, diffusion from the source neighborhood to the around. Thus, it will discuss in the details by comparison with VT-seismic activity.
The deformation at Arimura in Stage E is interpreted as delay response by decline of the magma or strain relaxation by stress (pressure) relaxation of intrusion magma. But, These at other sites don't do an exponential change until about October, 2015. We will estimate stress field to make a comparison

between the overlaps and after-VT seismicity, became active a little at slightly remote resion from source in September to October, 2015.
The density of fluid in the crack just after the intrusion is estimated at $0.98\pm0.37 g/cm^3$ (Kazama et al., 2016). It seems to be very foaming advanced magma. Therefore, we will consider whether it can interpret above characters by upward or lateral gas diffusion.

Keywords: Sakurajima volcano, magma intrusion, viscoelastic response

Absolute gravity signals at the Sakurajima volcano since 2009 through 2016

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In this paper, we present gravity signals based on continuous absolute gravity measurements since 2009 through 2016. During this period, several hundreds to a thousand eruptions/explosions were observed every year until July 2016. In particular, significant seismicity and crustal deformations were observed on Aug. 15, 2015, followed by unusual quiescence since August 2015.
Gravity signal after eliminating groundwater disturbance showed remarkable features during several major volcanic events, such as (1) vulcanian eruption from the Minamidake A crater on July 24, 2012, (2) formation of lava dome at the Showa crater in January to February 2015, and the dyke intrusion events on Aug. 15, 2015.
Correlation between the two time series of gravity change D*g*(*t*) and tilt/strain changes D*e*(*t*) is essential to discuss the volcanic process of these events. For example, time lag between D*g*(*t*) and D*e*(*t*) is negligibly small during the dyke intrusion (Aug., 2015) while D*g*(*t*) during the other period shows significant time lag (~1 day) to D*e*(*t*). In addition the amplitude ratio |D*g*/D*e*| during the dyke intrusion event assumed a value expected from the dislocation theory, while it is 100 times larger than the expectation during the other events. These characteristics are well explained in terms of the conduit status (open/closed). When the conduit is closed as in the case of the dyke intrusion event, both strain/tilt and gravity are principally governed by instantaneous elastic deformation, which implies absence of time lag. On the other hand, when the conduit is open as in the explosion period other than the dyke intrusion event, inflation/deflation of magma chamber does not cause effective elastic deformation, which means larger |*g*(*t*) / *e*(*t*) | compared to the case of closed conduit and significant time lag of *g*(*t*) to *e*(*t*) because magma migration in a conduit requires certain amount of time.

Keywords: Gravity, Sakurajima volcano, conduit

Temporal change in transfer function using ACROSS associated with magma intrusive event in 2015 in Sakurajima volcano, Japan

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We detected a temporal change in propagation property of seismic wave associated with a magma intrusive event on 15 August 2015 of Sakurajima volcano, Japan. The propagation property, which is called transfer function (Green’s function), has been monitored continuously since 12 September 2012 using an accurately-controlled seismic source (ACROSS) and seismic stations in Sakurajima volcano island. The change in the transfer function was calculated with 2-hour resolution. Large change is detected in the initial stage of the intrusive event, when the rate of crustal deformation was maximum. The amount of change associated with the intrusive event shows a spatial variation, depending on the location of the seismic stations. We calculated cross covariance between the transfer functions before and after the event. The cross covariances for the stations near the craters of 1914 Taisho eruption show larger reduction than those in the peripheral area even for the stations of comparable distance from the ACROSS source. The stations that show large reduction of cross covariance also show phase advance toward coda part, meaning velocity increase of the media. The amount of velocity increase is estimated to be about 1%. This indicates that the velocity increase is caused by the stress increase due to the magma intrusion. The stations in the peripheral area, which shows little reduction of cross covariance, also show little velocity change even in the same direction from the intrusion source. This may result from spatial variation of stress sensitivity of the medium in the volcanic body. The material near the Taisho craters of Sakurajima volcano is more sensitive to stress probably due to less compaction of eruption material.

Keywords: Temporal variation of seismic velocity, Scattering of Seismic wave, Stress Sensitivity

The final round of the repeating seismic experiment in Sakurajima Volcano, Japan. The experiment 2016.

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1. Akita University, 2. Kyoto University, 3. Hokkaido University, 4. Tohoku University, 5. Tokyo Institute of Technology, 6. University of Tokyo, 7. Nagoya University, 8. Kyushu University, 9. Kagoshima University, 10. Japan Meteorological Agency

The final round of the repeating seismic reflection experiments in Sakurajima Volcano and their summary are presented. The experiment series aims detection of structural evolution associated with underground magma movement in Sakurajima Volcano, which is a project included in the national project "the Earthquake and Volcano Hazards Observation and Research Program". The experiment is the first seismic experiment after the 2015 intrusion event, which was carried out after two years of the previous round. Seismic experiments have been performed every Decembers since 2009 with the identical geometry in the northern and eastern part of Sakurajima. Two major lines are routinely included and comprise 14 shot points and 225 stations in these experiments. Another line were also deployed in 2016 in the east foot of Minamidake with additional 20 stations for the purpose of detection of change in seismic response around the 2015 intrusion area. Uniform instruments, LS-8200SD by Hakusan Industry and Vertical motion 4.5Hz sensor, and 20kg size chemical explosions are used. The detonations for the final round experiment was done on 8th December 2016. 98.4% of all stations were completed schedule and seismograms up to 13 Gbytes were obtained through the experiment.
Tsutsui et al. (2016, JVGR) compiled seismic sections through six years, and presented that there is a reflector which changes associating with volcanic activity at depth of 5.8km below sea level. The reflector, Alpha, located beneath northeast Sakurajima, in the north of the known pressure source presented by Iguchi (2013, BVSJ). Tsutsui et al. (2016, JVGR) presented that the reflectivity of Alpha built up as the intrusion event in 2009 - 2010, and was fading after. The reflector did not respond the second intrusion from 2011 through 2012.
Further considerations on data in cross-line observations for seven rounds revealed three more clear later phases. Those were presented by Tsutsui et al. (2016, JpGU meeting).
1) A clear PS conversion from 5.8 km depth appears in 2012,
2) A clear PP reflection from 4.7 km depth appears in 2009,
3) A clear PP overcritical reflection from 2.4 km depth appears in 2012.
All of these are located in two kilometer south of reflector Alpha and their locations are coincident with the known pressure source by Iguchi et al. (2013).
Data of 2016's experiment suggest that intensity of several reflectors has changed after the previous round as followings ;
1) The reflector at 5.8 km depth has faded.
2) No PS conversion from the reflector at 5.8 km is detected.
3) Enhanced reflection from 4.7 km depth.

4) Enhanced reflection from 2.4 km depth.
The facts suggest there was structural evolution possibly associated with the 2015 intrusion beneath Sakurajima Volcano.

This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its Earthquake and Volcano Hazards Observation and Research Program, also supported by Japan meteorological Agency and DPRI, Kyoto University. The instruments for routine experiment are provided by Earthquake Research Institute, University of Tokyo.

Keywords: Sakurajima Volcano, Reflection seismology, Magma

Shallow crustal velocity structures obtained from ambient seismic noise study in the Aso caldera

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The Aso volcano is situated approximately in the central of Kyushu and is one of the most active volcanoes in Japan. There were four gigantic eruptions occurred and present caldera was formed about 89 ka known as Aso-4 eruption, with around 18 km in E-W and 25 km in N-S direction. Recently, the major volcanic activities focus on the post-caldera central cones, especially the first crater of the Mt. Nakadake. The conceptual volcanism and magma plumbing system of the Aso volcano were investigated with various geophysical and geodesic observations. The magma chamber is approximately spherical, located 3–4 km southwest of Mt. Nakadake (around Mt. Eboshidake) at depths of 6-10 km. Fumaroles and surface geothermal activities also expose in the southwest flanks of Mt. Eboshidake.

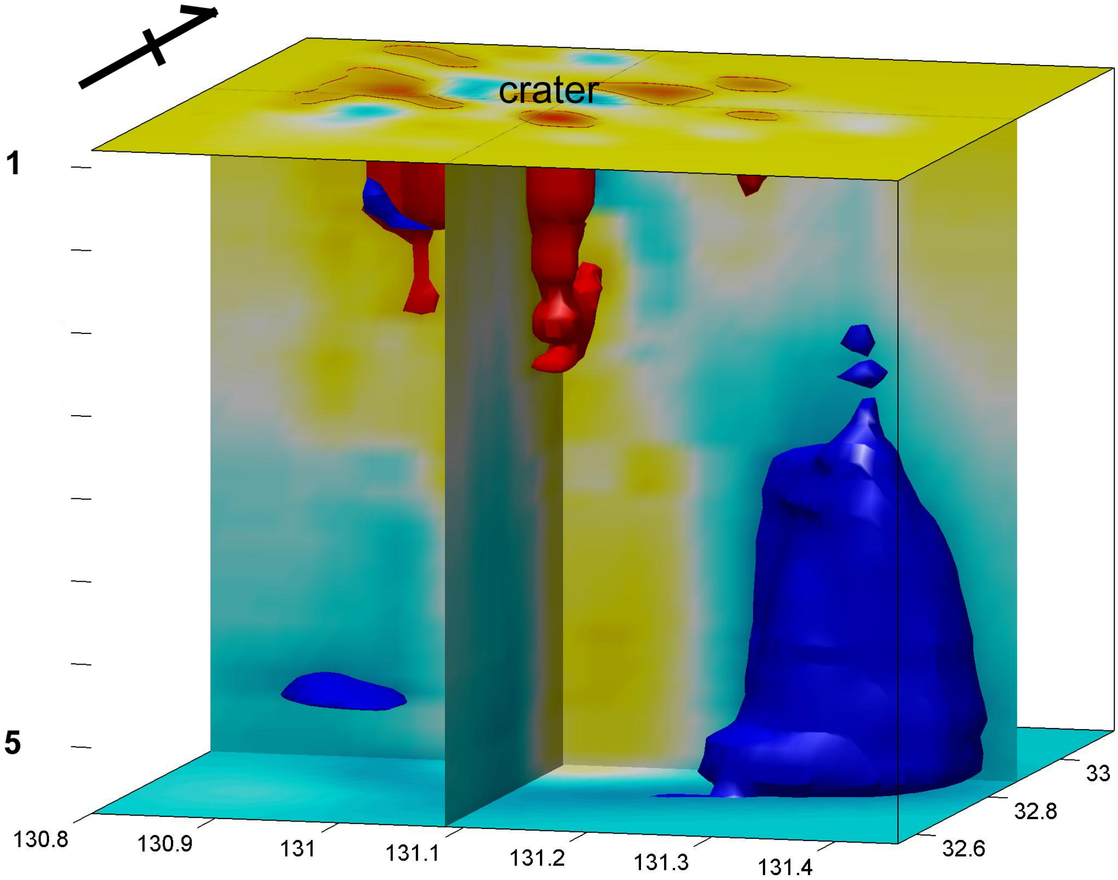
Analyzing ambient seismic noise signals has been routinely used to investigate the subsurface shear-wave velocity structure around the world in the past decade. Some studies also demonstrated it is possible to monitor the magma and hydrothermal fluid movement, or seismic velocity variations beneath active volcanos from the temporary changes of cross-correlation functions (CCFs). The seismic activities of Aso volcano have been monitored with around 20 broadband and short-period seismometers operated by Aso Volcanological Laboratory (AVL). The seismic dataset also included five permanent broadband stations operated by Japan Meteorological Agency (JMA) or National Research Institute for Earth Science and Disaster (NIED), which are located inside and surrounding the Aso caldera.

The interstation distances are much shorter (1-2 km) near craters on the Mt. Nakadake comparing with station-pairs surround the Aso caldera (10-20 km). Seismic data is daily vertical component between November 2009 and September 2013, i.e., before recent eruptions started on 25 November, 2014. Raw data were firstly transferred from WIN to SAC format and downsampled to 20 Hz. After primarily checking data quality, the daily CCFs were obtained in the 1-10 s period band for broadband station-pairs and 0.2-5 s for short-period station-pairs. Daily CCFs were stacked monthly, and then monthly CCFs were stacked again to further obtain Rayleigh wave phase velocity dispersion curves. The 2D and 3D phase velocity maps were mainly constructed in the 1-5 s period band and to determine the predominant velocity distributions.

Generally speaking, Rayleigh waves are sensitive at depths approximating one-third of wavelengths and vary with periods. Therefore, the sensitive depths of S-wave velocity structures ranged from approximately 0.7-5 km in this research. At most of periods, low velocities are dominant underneath the post-caldera central cones and the western portions of the Aso caldera, which might be corresponding to magma conduits and geothermal activities. High velocities are observed in the east of Mt. Nakadake and also the regions surround the Aso caldera, which might be related with much earlier volcanic activities that stopped recently.

The obtained velocity structures in this study can be as a reference, which were obtained with seismic data before latest eruptions. More recent seismic data should be easier to observe temporary variations of daily CCFs, which might be related to the movement of magma or hydrothermal fluid that cause temporary velocity structural variations in the shallow crust. More dense seismic stations might be required to image more detail 3D velocity structures and temporary variations.

Keywords: ambient seismic noise tomography, Aso caldera, shallow crust


crater
1
5
130.8
130.9
131
131.1
131.2
131.3
131.4
32.6
32.8
33

Ground deformation source model at Kuchinoerabu-jima volcano during 1995–2014 as revealed by repeated GPS observation

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We analyzed repeated GPS observation data in Kuchinoerabu-jima during August 1995–April 2014. Most stations located around the Shin-dake crater showed crater-centered radial horizontal displacements. There was a tendency that observed horizontal displacements at western rim of the Shin-dake crater were larger (16.6–20.6 cm) compared to those at eastern rim (7.8–11.6 cm). In addition, station KUC14 which locates approximately 500 m south of the Shin-dake crater showed westward horizontal displacement rather than crater-centered radial (southward) one. On the other hand, small displacements (less than 2 cm) were detected at the stations located at the foot of Kuchinoerabu-jima. We modeled the observed displacements. In order to take topographic effects into account, we applied a finite element method (FEM) using the software Flex PDE Professional version 6.40. We set entire FE domain as 100×100×50 cubic kilometers (129.7011–130.7351˚E, 29.9911–30.8994˚N, 0–50 km bsl). We set top of the domain as a free surface, and sides and bottom of the domain as fixed boundaries. Since we used stations inside Kuchinoerabu-jima in the present study, topography was introduced in the area within Kuchinoerabu-jima using DEM data provided by Kagoshima prefecture, and elevation of the outside area was assumed to be sea level (zero). We assumed a homogeneous elastic rheology with a shear modulus of 30 GPa and Poisson's ratio of 0.25. We applied a vertical spheroid source model and searched optimal values of horizontal location, depth, equatorial and polar radiuses, and internal pressure change of the source which minimize the RMS between observed and calculated displacements using the forward modeling method. A spherical source with 100 m radius (i.e., both equatorial and polar radiuses are 100 m) was obtained beneath the Shin-dake crater (130.2157˚E, 30.4462˚N) at a depth of 310 m asl (i.e., the uppermost part of the spherical source is approximately 100 m below the crater bottom). The pressure increase of 831 MPa yields volume increase of 90 thousand cubic meters. Taking topographic effects into account allowed the reproduction of large horizontal displacements at western rim of the Shin-dake crater and westward horizontal displacement at KUC14. The location of the obtained spherical source coincide with the demagnetized ellipsoid estimated by Kanda et al. (2010, JVGR). They interpreted that piezomagnetic variation was produced by the pressurized rocks around the aquifer due to the continuous supply of high-temperature volcanic gases in addition to the thermal effect. The obtained spherical source may be corresponding to the pressurized aquifer.

Keywords: Kuchinoerabu-jima volcano, ground deformation, GPS, finite element method

Geodetic Constraints on Post-eruptive deformation of 2014 eruption on Ontake Volcano

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ALOS-2 / PALSAR-2 data revealed that post-eruptive deflation over a small region of Jigokudani crater has been continuing. It started immediately after the 2014 phreatic eruption on Ontake Volcano. This deflation was clearly triggered by 2014 phreatic eruption, so this indicates pre-existing reservoir at the shallow depth beneath Jigokudani crater. In the pre-eruptive stage, hydrothermal fluid should have accumulated in this shallow reservoir. So, InSAR analysis of this deflation signal contributes to understanding pre-eruptive process in the pre-existing reservoir. Our aim is to understand the mechanism of the deflation and to constrain pre-eruptive process in the shallow reservoir beneath Jigokudani crater.

The result of InSAR analysis for pairs corresponding to post-eruptive deformation shows a typical spatial pattern of deflation over Jigokudani crater during 2014-2016. Characteristics of inversion result using half-space point source are as follows. Depth of deflation source ranges between 400-750m beneath Jigokudani crater. Total amount of volume change of the source is 6-7×$10^5 m^3$ during 2014-2016. In order to evaluate topographic effects on ground deformation which might be significant in the region with complex terrain, we built a three-dimensional finite element model of Ontake Volcano. We carried out finite element computation and found that topographic effect is negligible from viewpoint of estimating source depth and the amount of volume change.

Assuming that the post-eruptive deflation is caused by discharge of hydrothermal fluid accumulated in the pre-existing reservoir, total mass of hydrothermal fluid emitted from the shallow reservoir, corresponding to the amount of volume change of the deflation source, is less than that of plume emitted from vents during September 2014-November 2014. This indicates that a large part of water mass emitted from eruptive vents must be originated from not the deflation source but deeper part of Ontake Volcano.

Assuming that accumulation of hydrothermal fluid inside the deflation source was triggered by 2007 dike intrusion event, an increase of GNSS baseline length between Otiai- Tanohara must be 3 cm during 2007-2014, but actually, such increase has not been observed. This suggests that accumulation of hydrothermal fluid inside the deflation source of the 2014 eruption almost completed by 2007 eruption accompanying dike intrusion event.

Keywords: Ontake Volcano, Phreatic Eruption, InSAR, Ground Deformation

Volcanic deformation of Atosanupuri volcanic complex in the Kussharo caldera, Japan, from 1993 to 2016 revealed by JERS-1, ALOS and ALOS-2 radar interferometry

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1. GSI of Japan, 2. Hokkaido Univ., 3. Kyoto Univ., 4. JAXA

A series of inflations and deflations of a volcanic complex in the Kussharo caldera, eastern Hokkaido, Japan, was revealed by interferometric analysis using archived satellite synthetic aperture radar data. A time series of interferograms from 1993 to 1998 showed the evolution of a ground deformation process. The horizontal dimension of the deformation field is about 10 km in diameter, and the largest amplitude of the deformation is approximately 20 cm. The inflation occurred in 1994 and a simultaneous earthquake swarm activity was observed just around the inflation area, however, there was no other observation related to the deformation. The inflation was then followed by a deflation and the deflation is a mirror image of the inflation. Model simulations suggest that the deformation was caused by a source at a depth of about 6 km and the position of the source did not change throughout the episode. In addition to the main sequence of the inflation-deflation, there is a smaller scale deformation structure at the center of the deforming area. The small scale and constant rate deformation on lava domes was still observed 20 years later by a new satellite.

Keywords: Kussharo caldera, Atosanupuri volcanic complex, Volcanic deformation, InSAR, JERS-1, ALOS, ALOS-2

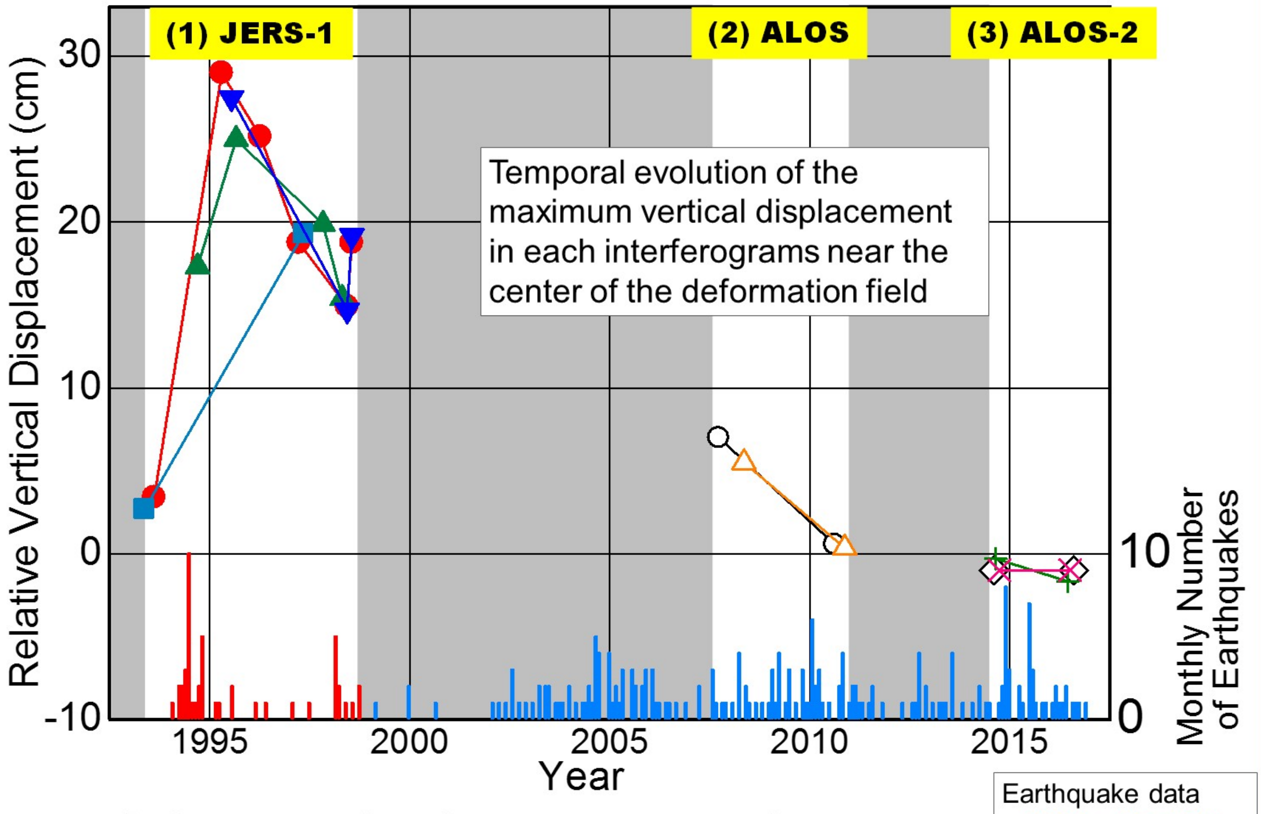

Fig. 1 Series of inflation and deflation

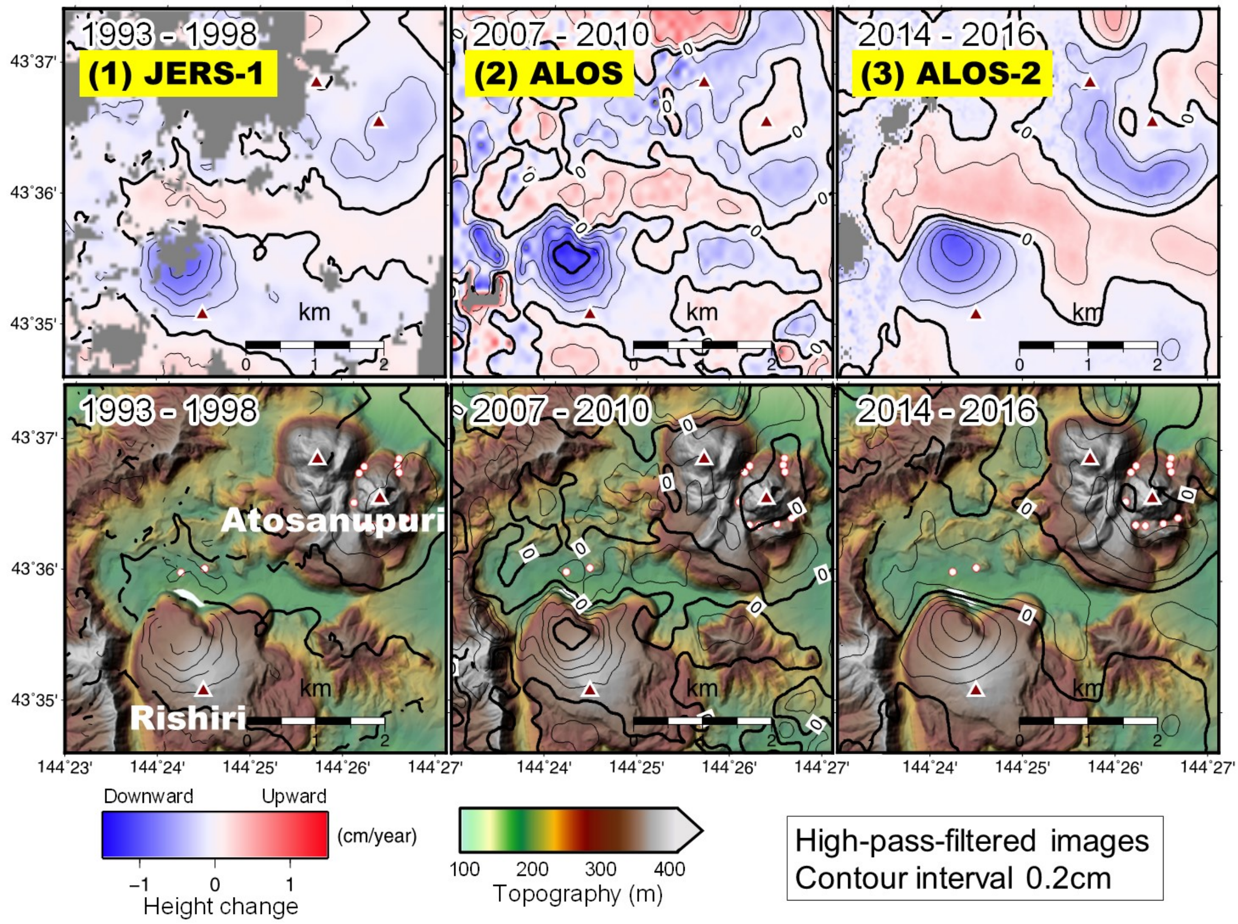

Fig. 2 Average images of small scale deformation

Ground Deformation at Campi Flegrei caldera, Italy, revealed by InSAR analysis of ALOS-2/PALSAR-2

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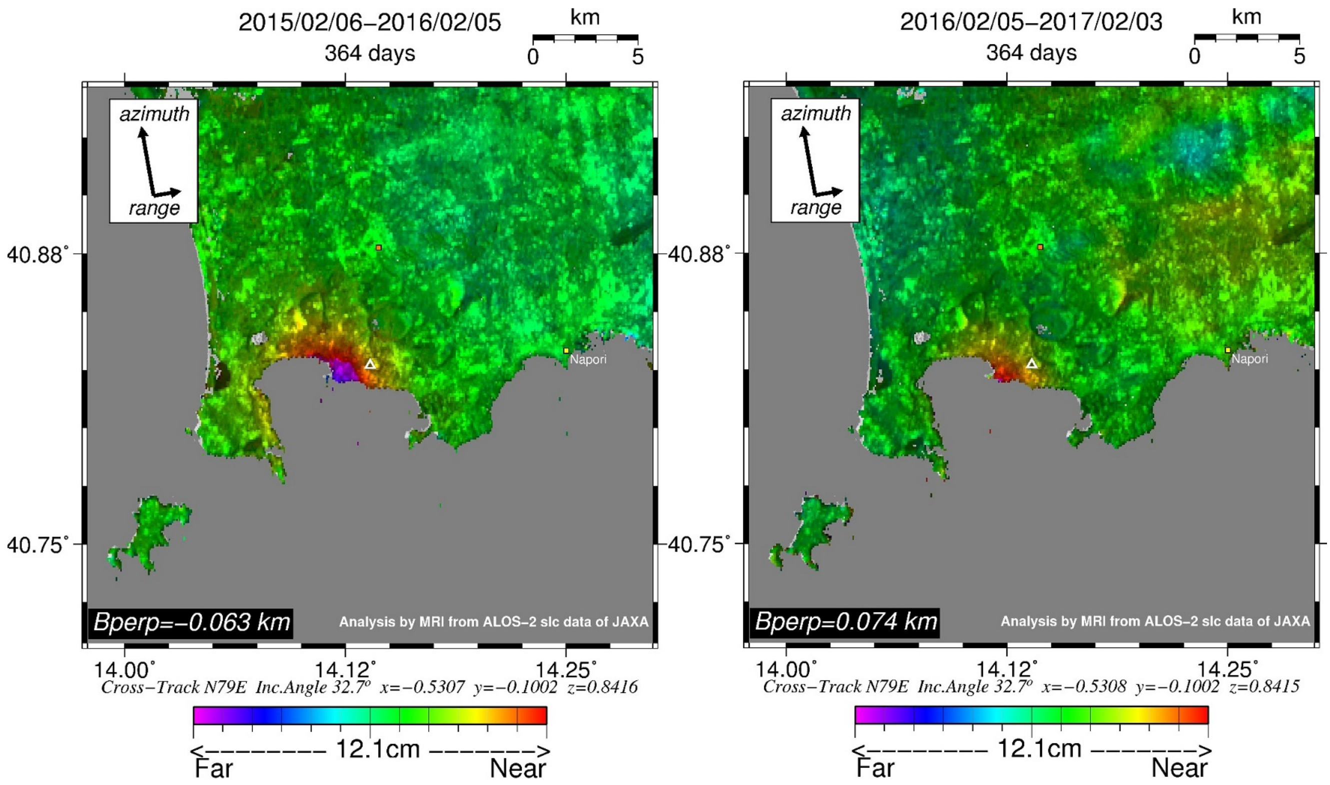
Campi Flegrei caldera in Italy is also close to the metropolitan area of Naples and is one of the regions with the world's highest volcanic risks. The most recent eruption continued for 8 days in 1538 when Mt. Monte Nuovo was formed (VEI = 3). Since then, no eruption has occurred for about 500 years, but expansion and contraction of ground deformation have been reported frequently by GNSS analysis and interference analysis using SAR satellites (for example, Lundgren et al. (2001) And Troise et al. (2007)). Recently, several data showing expansive crustal deformation around Pozzuoli Bay have been reported and it is suggested that active volcanic activity is still continuing (Martino et al. (2013) and D 'Auria et al. (2015) etc). In addition, Chiodini et al. (2016) suggest that magma could be approaching the critical degassing pressure at Campi Flegrei and where accelerating deformation and heating are currently being observed.
ALOS-2, was launched on May 24, 2014, has an L-band SAR (PALSAR-2) and survey all over the world. We performed interferometry analysis using ALOS-2/PALSAR-2 data surveyed after 2014, detected the ground deformation of Campi Flegrei caldera, and tried estimating underground pressure source. As a result, it was found that the ground uplift of about 10 cm was detected in the interferometry analysis of the both orbit between 2015 and 2016, and the ground deformation can be explained by assuming a Mogi point source of about 4.6 $\times 10^6$ m^3 to about 3.8 km below the sea level. Furthermore, the InSAR analysis using pairs from 2016 to 2017 also detected the displacement up to about 6 cm toward the satellite can be seen around Campi Flegrei caldera, suggesting that the ground uplift is continue.
PALSAR-2 data were prepared by the Japan Aerospace Exploration Agency (JAXA) and were 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. In the process of the InSAR, we used Digital Ellipsoidal Height Model (DEHM) based on the Shuttle Radar Topography Mission (SRTM 4.1) provided by Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR), and Generic Mapping Tools (P.Wessel and W.H.F.Smith, 1999) to prepare illustrations.

Keywords: ALOS-2/PALSAR-2, InSAR, Campi Flegrei caldera, Ground deformation


2015/02/06–2016/02/05
364 days
km
0
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azimuth
range
40.88˚
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Bperp=–0.063 km
Analysis by MRI from ALOS–2 slc data of JAXA
14.00˚
14.12˚
14.25˚
Cross–Track N79E Inc.Angle 32.7° x=–0.5307 y=–0.1002 z=0.8416
<--------- 12.1cm -------->
Far
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2016/02/05–2017/02/03
364 days
km
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40.88˚
40.75˚
Napori
Bperp=0.074 km
Analysis by MRI from ALOS–2 slc data of JAXA
14.00˚
14.12˚
14.25˚
Cross–Track N79E Inc.Angle 32.7° x=–0.5308 y=–0.1002 z=0.8415
<--------- 12.1cm -------->
Far
Near

Monitoring volcanic activity from space by ALOS-2 (Daichi-2) / PALSAR-2 data

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1. GSI of Japan

The Geospatial Information Authority of Japan (GSI) has conducted to monitor ground surface deformation of earthquake, volcanic activity, subsidence and landslide throuhtout Japan by interferometric SAR (InSAR) analysis using ALOS-2 (Daichi-2) /PALSAR-2 data.
ALOS-2 is routinely observing the whole area of Japan both in ascending and descending orbits three to four times a year following basic observation schedule designed by JAXA. Every time observation data is newly acquired, GSI always conducts InSAR analysis of the data combined with the former data which have the same path and the same observation mode. In the sequence of the analysis, we also conduct tropospheric error reduction with numerical meteorological model of Japan Meteorological Agency (JMA) and reduction of long wavelength error with GNSS solutions of GNSS continuous observation system (GEONET).
Images obtained from InSAR analysis (hereinafter referred to as "SAR interferogram") are formated into tile data, and can be browsed on a web map of GSI, "GSI Maps". GSI Maps enables us to superimpose SAR interferograms on various geospatial information provided by GSI such as topographic maps, aerial photographs, volcanic land condition maps and so on. This visualization enable us to easily compare SAR interferograms to other information like topography and geology and more robustly identify an area of ground surface deformations on the SAR interferograms.
We are monitoring 97 volcanoes in the domestic land including the Northern Territories using SAR interferogrms of ALOS-2 and reporting crustal deformation detected by the interferograms to regular meetings of the government expert committee, Coordinating Committee for the Prediction of Volcanic Eruption. In addition to the regular observation, in case of significant activities of volcanos such as eruptions, urgent observation of ALOS-2 is requested to JAXA by Volcano WG (JMA for the secretariat) of the demonstration experiment for disaster prevention by Earth Observation Satellite. If the urgent observation is conducted based on this request, GSI emergently analyzes the data, provides the SAR interferograms to Coordinating Committee for the Prediction of Volcanic Eruption and open the interferograms to the public as necessary.
In this presentation, we report monitoring of ground surface deformation, especially monitoring of volcanoes, by InSAR analysis using ALOS-2 data, which the GSI is working on.

Keywords: InSAR, ALOS-2, monitoring ground surface deformation, volcanic activity

MODVOLC - monitoring Earth's sub-aerially active volcanoes from space since 2000

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The MODVOLC system (http://modis.higp.hawaii.edu) uses the two MODIS sensors carried onboard NASA’ s Terra and Aqua satellites to monitor the Earth’ s volcanoes for evidence of thermal unrest. Primarily sensitive to the presence of active lava, the system has detected, monitored, and recorded the thermal emittance from eruptions at 107 volcanoes since the system became active in February 2000. This presentation will cover, 1. How the algorithm works and the re-designed webpage that allows anyone to access and interrogate the global 17 year archive; 2. Some interesting results that have been obtained from analysis of the data including evidence for periodicity in eruptions at some volcanoes, and general differences in magnitude and intensity of thermal emission from lava domes, flows, lakes and fountains.

Keywords: Remote sensing, volcanology, MODIS

Integrated offshore investigations in the vicinity of Kikai Caldera, southwestern Japan —towards a comprehensive understanding of destructive caldera eruptions—

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1. Kobe University, 2. Japan Agency for Marine-earth Science and Technology (JAMSTEC), 3. Tokyo University of Marine Science and Technology

Integrated offshore geophysical and geological investigations have been started to understand the mechanism of catastrophic caldera-forming eruption (CCFE) of the Kikai Caldera, SW Japan, which caused the latest CCFE on the Earth at 7.3ka. This caldera has been focused as it is a submarine caldera allowing to conduct dense seismic structural survey that is required for imaging and monitoring a large magma reservoir beneath this caldera. In the Oct. 2016, Kobe University and JAMSTEC conducted bathymetric survey with multi narrow beam echo sounder (MNB), geomagnetic survey with a proton magnetometer, multi-channel reflective seismic survey (MCS), and deployments of ocean bottom seismometer (OBS) and electro-magnetometer (OBEM) in "the 1st KOBEC exploration cruise" by the training vessel "Fukae-maru "belonging to Kobe University. The MNB survey revealed detailed bathymetry in the vicinity of the caldera. The bathymetric change from data obtained in the past bathymetric survey by Japan Coast Guard (2008) will be discussed in the presentation. In addition, acoustic pressure anomalies within the seawater rooting to the seafloor observed at the several areas in the margin and inside of the caldera. They are interpreted as hydrothermal anomalies relating to volcanic activities. The MCS surveys were conducted beneath 4 survey lines across the caldera. The reflection profiles show dense layered subsurfaces outside of the caldera while reflective planes are hard to be recognized inside of the caldera. Faults and disconformities are recognized in the several locations. Preliminary geological interpretation will be also discussed in the presentation. The OBSs and OBEMs will be retrieved in the 2nd exploration cruise in March 2017 by "Fukae-maru". In the 2nd cruise, we also plan to conduct direct seafloor observation by a remotely operated vehicle (ROV) named "Shindai-2K". In addition, we will deploy 4 OBEMs which equip absolute pressure gauge to detect vertical geodetic displacements and to image electrical resistivity structure which may reveal magma reservoir beneath the caldera (e.g. Hill et al., 2009).

K-Ar age connected with initial Ar isotopes and anomalous noble gas isotope ratio, observed in eruption

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The ZAO volcano, which is classified stratovolcano volcano, is located the central Northeast Japan area, and has been active since ca. 1 million years ago approximately. The newest stage started about ca. 35ka. Pyroclastics dominate in this stage. They are further classified into 5 parts: the Kumanodake pyroclastic rocks, the Komakusadaira pyroclastic rocks, the Kattadake pyroclastic rocks, the Umanose agglutinates, the Goshikidake pyroclastic rocks. this newest The volcanic products in the newest stage are classified into medium-K and calc-alkali series of basaltic andesite to andesite, which are regarded to be formed by mixing between felsic and mafic magma in many cases (e.g. Takebe et al., 2015).
The un-spiked Potassium-Argon dating (sensitivity method, i.e. peak-height comparison) can be combined with comprehensive noble gas analysis protocol. When the magma (melts) solidify, it is critical that the initial Ar isotope ratio reaches equilibrium with atmospheric composition. In case that disequilibrium and/or kinetic effect are suggested from isotopic fractionation resulted to the altered initial Ar isotopic ratio from recent atmosphere, the corrected initial isotope ratios were applied to the calculation using with un-spiked K-Ar method. Although Kaneoka (1980) reported that the chemical composition of igneous rock and eruptive condition affect to the noble gas composition, there is a little example of analytical data. Thus, it is necessary to confirm the noble gas isotopic ratio and abundance.
The Zao magmatism of newest volcanic products was reported in Takebe et al. (2009); the respective K-Ar ages of the Komakusadaira pyroclastic rock, the Kattadake pyroclastic rock, Umanose agglutinate is about 30-57ka (one outlier is 100ka), 13ka and 5ka. The newest volcanic products of Zao volcano (the Goshiki pyroclastic rock, the Komakusadaira pyroclastic rock) including historic lava and the neighboring hot spring waters were analyzed by standard noble gas analysis method. We selected and analyzed both low bubbled and high-bubbled sample from each stratigraphy. The noble gas isotopic analysis is performed by noble gas mass spectrometer, GVI-5400He (GV Instruments Co.), in JAMSTEC. We contrived to reduce the atmospheric contamination to sample by using the 60-80 mesh size usually applied to the K-Ar dating. The He isotope ratio was calibrated by the Kaminoyama hot spring gas collected in 1983 (Hanyu and Kaneoka, 1987; Kumagai 1999, Tamura et al, 2005). As the working standard for reference of heavier noble gases for 20ka and older, the age standard samples of YZ-1 (227ka; e.g. Takaoka, 1989; Nagao et al., 1991) from Zao volcano and of MZ-94 (326ka; Iwata et al, 2009) from south Zao volcano were applied.
In terms of the heavier noble gases than Ar, i.e. Kr, Xe, their isotope ratio is similar to the atmospheric ratio; however, their abundance is much concentrated i.e. 10-100 times higher than the atmospheric abundance, even the. Kr and Xe isotopic ratio of YZ and MZ94 having significant anomaly contrasted to the atmospheric ratio. Otherwise, we tried to find the contribution from magmatic composition using He isotopic ratio. Therefore, we tried to clarify any contribution from surface environment for magmatic noble gas in the newest volcanism of Zao volcano.

Keywords: Zao, volcano, K-Ar dating, isotope ratio, Helium

Eastimate of alkalie basalt magma H_2O content in Kannabe volcano

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1. Introduction
Alkaline basaltic volcanism widely occurred in the Chugoku area, southwestern Japan, from Paleogene to Quaternary. Although major, trace, and isotopic compositions of these volcanic rocks have been intensively analyzed, detailed magma differentiation processes have not been examined on the basis of a petrologic study. Here, we conducted thin section observations and determined bulk-rock and mineral compositions of Quaternary-Kannabe alkaline volcanic rocks in order to reveal crystallization differentiation process. Consequently, we concluded that H_2O content in Kannabe magma was ˜1.6wt%, which is half as low as the estimation in the previous study.
2. Kannabe volcano : Hidaka Lava, Arakawa Lava, Jugo Lava, Shiwagano Lava
Eruption age of Kannabe volcano acted between 25ka˜7.3ka because Kannabe volcano is sandwiched between AT and K-Ah tephra. Kannabe volcano consists of four lava flows erupted from different volcanic centers: Hidaka Lava, Arakawa Lava, Jugo Lava, and Shiwagano Lava in order of age. Bulk-rock SiO_2 contents of Hidaka, Arakawa, Jugo, and Shiwagano Lavas are 48.8-49.1 wt%, 48.9-50.0 wt%, 49.3-50.1 wt%, and 48.8-50.0 wt%, respectively, and MgO contents of those lavas are 6.8-7.1 wt%, 6.5-6.9 wt%, 6.5-6.6 wt%, 6.5-7.2 wt%, respectively. MgO contents monotonically decrease from Hidaka Lava, through Arakawa Lava, to Jugo Lava, whereas Shiwagano Lava covers whole compositional range of the other three lavas. Compositional trend of major elements observed for four lavas can be reproduced by fractional crystallization of olivine, clinopyroxene, plagioclase, and titanomagnetite.
Four lavas have relatively small amount of phenocrysts (<˜10vol%). Most of those phenocrysts is olivine. Glomeroporphyritic structure of olivine and plagioclase was confirmed. Olivine which has kink band was not confirmed. All phenocrysts shew normal zoning from analyses of Electron Probe Micro Analyzer, and observation of backscattered electron image. Cores of olivine and plagioclase phenocrysts shew Fo# [=100Mg/$(Mg+Fe)_{mol}$] = 70˜86 and An# [=100Ca/$(Ca+Na)_{mol}$] = 60˜78, respectively. Cores of plagioclase phenocrysts have two peaks of An# = 78 and 66 in the frequency diagram of An#. The plagioclase phenocryst of An# = 66 is pure and shows euhedral, but the plagioclase phenocryst of An# = 78 has pollution zone inside it. On the other hand, olivine and plagioclase of glomeroporphyritic structure shew Fo# = 76˜78 and An# = 64˜68, respectively. This result suggest that the plagioclase phenocryst of An# = 78 is not a phenocryst crystllized from same magma.
3. Consideration : Estimate of Hidaka Lava magma H_2O content
We estimated magma H_2O content for Hidaka Lava, which have the most MgO content in the four lavas and small plagioclase phenocryst volume (<˜1vol%), using a combination of these bulk compositions, plagioclase-liquid hygrometer (Lange *et al.*, 2009), and a geothermometer for olivine-saturated melts (Sugawara,2000 ; Medard and Grove,2008). When the pressure is 0.5GPa, 1.0GPa, the magma H_2O content is 1.3 wt%, 1.6 wt%, respectively. These results are less than magma H_2O content estimated by Zellmer *et al.* (2014). This cause is that Zellmer *et al.* (2014) estimates magma H_2O content using plagioclase which is not phenocryst and shows An# = 82.

Keywords: magma water content, the Chugoku area, alkalie basalt

Magma plumbing system of Fuji volcano inferred from product of latest summit eruption (Yufune-2 scoria)

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Because of no recent eruption in Fuji volcano, syneruptive geophysical observations have not constrained magma plumbing system. Petrological studies of past eruptive products thus have an important role. As a target, I have selected a latest summit eruption, 2200 years ago. Yufune-2 scoria, product of this eruption, has an eastern dispersal axis (Miyachi, 1988). Scoria samples were collected from an outcrop locating 10 km to the east of the summit. I have divided the scoria deposit into 5 units (a-e; 10, 90, 5, 15, 60 cm thickness, respectively), each of which is distinctive in scoria size. The scoria size increases upward between unit-a and unit-b, but decreases in the upper units. The change in scoria size implies those of eruption intensity and eruption column height, if wind direction and intensity did not change. Bulk rock composition of scoria (50.5-51.2 wt. % SiO_2) does not change with eruptive unit. To further characterize erupted basaltic magma, I have analyzed thin sections of 4-6 scoriae for each unit.
Except the xenolith of basaltic lava included in scoriae of unit-a (Suzuki and Fujii, 2010 JVGR), scoriae seem almost homogeneous regardless of the eruptive unit. Phenocrysts of olivine and plagioclase (less than 2mm) are euhedral and lack in reaction rims. As a whole eruption, Fo contents of olivine cores vary between 73 and 80, while An contents of plagioclase cores vary between 65 and 92. Core compositional distribution is distinctive in each unit. All scoriae of unit-b and c are dominated by low-Fo (<76) and low-An (<85) cores. On the other hand, unit-e scoriae and half of unit-d scoriae are characterized by cores of high-An (>85) and high-Fo (>76), although some scoriae show wide Fo variety extending to Fo73. In unit-a scoriae and rest of unit-d scoriae, cores of phenocrysts show wide compositional range (Fo73-80, An65-92). As a whole, rim compositions of phenocrysts have correlation with compositional distributions of phenocryst cores.
Phenocrysts are divided into two types depending on dominant core composition. High Fo (>76) olivine and low Fo olivine (<76) have no overlap in composition and have similar crystal size. High An plagioclase (>85) has homogeneous core and is characterized by small crystal size (less than 500 μm). On the other hand, low An plagioclase (<85) rarely includes high An (>85) region in the center of the core. The high An (>85) region resembles the high An type in size. Scoria only with high Fo olivine and high An plagioclase (e.g. unit-d) have clearly lower amount of phenocrysts (3 vol. %) than scoria with only low Fo olivine and low An plagioclase (e.g. unit-b, c; 18-19vol. %).
These lines of evidence indicate that 1) magmas with different degree of crystallization (two endmembers), but with the same bulk composition, were present in the magma plumbing system just before the eruption, and 2) the two endmembers were erupted independently or mixed. Mixed magma erupted in unit-a. Then, the high-crystallinity part erupted without mixing in the climax (unit-b and unit-c). In the ending stage (unit-d and unit-e), less-crystallized magma erupted, accompanied by mixed magma. It is highly possible that the high crystallinity magma was derived from the less crystallized magma, judging from the continuous core composition of phenocrysts. I could identify the parts that crystallized when crystallinity was low only for plagioclase, not for olivine This can be explained by much more sluggish diffusion of CaAl-NaSi in plagioclase in comparison with Mg-Fe in olivine. More examination of diffusion profiles (including other elements) is necessary in order to constrain the timescale from the generation of high-crystallinity magma to the final ejection. It is also important to discuss the storage depths of two endmember magmas by the H_2O analyses of melt inclusions in phenocrysts (Yasuda et al., 2014) . At present, only rough estimation is available. Near-liquidus coexistence of olivine and plagioclase in the

melt of the groundmass composition requires less than 2.5kbar and H2O content of ca. 1.5wt.%, and 1110-1120C, if QFM buffer is assumed.

Keywords: Fuji volcano, Yufune-2 scoria, Magma plumbing system, Phenocryst size, Phenocryst abundance, Magma mixing