Tilt and Volumetric Strain change observed around Lake Akan at November 24, 2016

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Integrated hypocenter database prepared by Japan Meteorological Agency (JMA) shows slight increase in number of earthquakes around Mt.Oakan in November, 2016. On November 24, earthquakes with low frequency component is observed continuously, which is followed by an earthquake felt at Akan region. Two tiltmeters at Mt.Meakan installed by JMA, on the other hand, showed tilt change synchronously with the earthquakes with low frequency component. Their magnitude and down-dip direction are in the order of 10^{-8}rad and northeast (toward Lake Akan and Mt.Oakan).

Such change were also observed at other stations around the region, namely, groundwater level sensor at Lake Akan (AK3: installed by GSH and Hokkaido Univ.), Sacks-Evertson strainmeter at Kussyaro (KUT: installed by Hokkaido Univ.) and Accelerometer at Hi-net station "Akan-Kita" (ANNH: installed by NIED). Takahashi et al. (2012) reports that the groundwater level around Mt.Meakan acts as volumetric strainmetor, hence we converted the groundwater level change to volumetric strain change accordingly. It should be noted that volumetric stain change at AK3 and KUT both show the compressive strain.

We estimated the pressure source from these observations assuming a deflating point source. The source is estimated at the south of Mt.Oakan. Its depth and volume change are estimated to be 15km and 2×10^6 m^3. Due to the NE-SW-wide distribution of the stations used for the estimation, the error in horizontal position of the source is larger in NW-SE direction. The deep source depth is required to explain the compressive strain at KUT, which is 20km away horizontally from estimated source, for the deflating point source exhibits compressive strain at region where $r<1.4D$ (r and D being horizontal distance from the source and source depth, respectively).

Keywords: Akan, tilt change, crustal deformation

An application of the ASL method to seismic activity at Tokachi-dake

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Hypocenter distribution of volcanic earthquakes in time and space is one of the important information in assessing volcanic activity. Low-frequency earthquake (LP events) and continuous tremor often occur at shallow part of volcano edifice. Those events are considered to have close relationships with volcanic fluids such as magma, water, and steam. However, since phase arrival times of those events are usually obscure, it is challenging to determine the hypocenter automatically.
Tokachi-dake volcano in Hokkaido has a number of LP and tremor events, along with increase in volcanic activity. To obtain precise hypocenter location of these events at Tokachi-dake, we adopt Amplitude Source Location (ASL) method (Battaglia and Aki, 2003). The ASL method is one of the hypocenter determination techniques that analyzes the amplitude ratio of seismic wave among different stations under the simple assumption on distance attenuation and isotropic radiation of high-frequency seismic signal. Since the ASL method doesn’t require precise picking of seismic wave arrivals, it is potentially effective for hypocenter determinations of LP events and continuous tremor.
For introducing an assumption of isotropic radiation of seismic waves, the ASL method usually treats high-frequency signals over than 5Hz. Since such high-frequency seismic signals strongly are affected by a shallow ground structure, we first estimate site amplification effect at each station at Tokachi-dake by using coda normalization method (e.g., Phillips and Aki, 1986). We used 10 local earthquakes that occurred around Hokkaido in 2013-2016, and estimated site amplifications at 8 seismic stations, including 3 stations operated by Hokkaido University. Site amplification factors at Tokachi-dake clearly increase around Taisyo and 62-2 craters. Then we tried to determine the source location of volcanic earthquakes using the ASL method. As a preliminary analysis, we assumed the hypocenter locates at a shallow part of the volcano, and performed two-dimensional search of epicenter by fixing a source at the surface of topography. Consequently, estimated epicenters of tested events are well distributed around 62-2 crater. This result roughly matches the hypocenter distribution reported by JMA. The spatial distribution of estimation error should be examined at first. Then we will extend the searching algorithm in depth direction to estimate more detailed source locations.

Keywords: ASL method, Tokachi-dake, volcanic earthquake

Comparison between crustal movement and seismicity in Izu Ohshima Island

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We observe not only a long period dilatation of a baseline but also a periodical contraction and dilatation of baseline in Izu Ohshima Island. We observe micro earthquakes around Izu Ohshima Island too. So, we compare between earthquake occurrence and baseline length.
We use JMA hypocenter catalogue from April,2002 to January,2017. The number of earthquakes are 9969. We check Magnitude-Cumulative plot. Then, we find good determination of earthquake larger than Magnitude 1.0. We use baseline length from GSI 96054 to GSI 96055. We average baseline length in each month. We count earthquakes in each month.
When we count earthquakes number in each month, sometime earthquakes number are large. 7 months are larger than 100 earthquakes. We divide 4 period in baseline. A is bottom to middle. B is middle to peak. C is peak to middle. D is middle to bottom. 4 months larger than 100 earthqukes are in period B. 3 months larger than 100 earthqukes are in period C. This means earthquake swarms occur in dilatation period.

Keywords: Izu Ohshima volcano, crustal movement, seismic activity

Characteristics of multi-component strainmeter in Izu-Oshima for medium to long term variation -- strain data comparison with GNSS observation --

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In order to study about volcanic deformation in Izu-Oshima, we installed a multi-component strainmeter in a borehole at SNB station located in the southwest part of the island in 2013. The depth of strain sensors is about 75m from the ground level, or 25m below the sea level. The instrument has four strain sensors oriented 45 degrees apart and measures horizontal linear strains in N34.2E, N10.8W, N55.8W and N100.8W as CH0 to CH3 respectively. Accumulated data of SNB strainmeter make it possible to research about characteristics for medium to long term strain variation. In this study, we compared the data with two kinds of reference strain field, one is estimated from GNSS observation and the other from a spherical pressure source model. For observation by a borehole strainmeter, it is important to know the instrument's response to the surrounding crustal strain variation. Comparison with the reference field is an effective tool for that.
For the data of the strainmeter at SNB, abnormal steps are corrected, as well as tidal strain and the effect of atmospheric pressure change. The first reference stain is estimated from GNSS positioning data of three stations within about 4 km from SNB. Average strain field near SNB is derived from the relative displacement of those GNSS stations as strain components e_{xx},e_{xy} and e_{yy} for each day, and linear strains corresponding to CH0 to CH3 of the strainmeter are calculated by coordinate transformation. The other reference stain is estimated from a spherical pressure source model. In Izu-Oshima, volcanic deformation in medium to long interval is approximated to the deformation caused by a spherical pressure source located underground. The accompanied strain at an arbitrary point can be calculated from the source parameters, the position and the volume change. From GNSS observation all around the island, MRI (2017) estimated the position of the pressure source, and also its volume change as time series, from which we calculated the strain fields at SNB. Comparing those two reference strains, CH1 components of both strain were very similar as well as CH2 in long term trend and variations of the period about a year for the interval from 2012 to 2016. It seems the strain estimation is good for these components.
Strain fields of CH1 and CH2 observed by the SNB strainmeter were inspected using the referenced strains. In CH2 data of SNB, we found a continuous long term extension and repeated contraction and extension of the period 1 to 1.5 years. They were very similar to those of the references, the maximum and minimum of the strain data occurred almost in the same days respectively. Their variation from 2014 to 2015 were about 6 micro-strain in amplitude for the strainmeter, about 4 for the estimation from GNSS and about 8 for the estimation from the pressure source. The similarity means that each strain data or estimation is roughly reliable. Contrary in CH1, we could not find the similarity in the variation of the period from 1 to 2 years. The comparison with the reference strain estimated from the GNSS observation nearby and the spherical pressure source model made it clear that CH2 of the strainmeter could be acceptable in monitoring of the medium to long term volcanic deformation of Izu-Oshima.

Keywords: Izu-Oshima Volcano, strainmeter, GNSS

Volcanic deformation caused by gas bubbles rising in the magma chamber: Application to periodic deformation at Izu-Oshima volcano

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Recent geodetic observation networks were succeeded in detecting volcanic deformations with high time-resolution in active volcano. These data can be used for understanding the volcanic activities. In this study, we present the temporal changes of volume increase of magma chamber due to gas bubble rising and try to apply it to volcanic deformation at Izu-Oshima volcano.
In a magma chamber, small gas bubbles rise due to their buoyance force. As the gas bubbles rise, the gas bubbles expand due to pressure difference between gas bubbles and surrounding melt. As the expansion of gas bubbles, the volume of magma increases. The amount of volume increase of magma chamber is depended on the ratio of bulk modulus of melt and rigidity of surrounding elastic medium. The gas bubbles rise in the magma with a velocity proportional to the square of the gas bubble radius. We calculate the temporal changes of the volume changes of magma chamber, assuming the initial condition that the gas bubbles homogeneously distributed in the magma. The results show that the volume of magma chamber increases with constant rate, at first. Then the rate of volume change gradually decrease with time.
We compare these results and volcanic deformation detected by GNSS observation network at Izu-Oshima volcano. The pressure source of this deformation was estimated at a depth of 4-5 km below sea level and the amount of volume increase of 10^6 m^3. Considering the gas bubble radius of 2×10^{-4} and the number density of gas bubbles of 10^8 m^{-3}, the amount of volume changes and time scale of volcanic deformation observed at Izu-Oshima volcano was expressed.

Keywords: volcanic deformation, Izu-Oshima, gas bubble

Intermittent volcanic tremor activity at Miyakejima volcano during April 2015 –March 2016

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Volcanic tremor is considered as a seismic signal generated by complex interactions of magmatic fluids with surrounding rocks, so that it provides clues to understand underground volcanic situations. Intermittent tremors began to occur beneath Miyakejima volcano in April 2015. After a quiet period of three months, the tremor activities increased in amplitude until December, and then rapidly decreased at the end of December, following with weakened intensity until March 2016. Even during a quiescent stage, volcanic tremor has appeared occasionally, however, this tremor episode shows a very regular and rhythmic pattern. We have investigated the tremor waveforms based on the Izu-Islands volcanic observation system operated by the Tokyo metropolitan government, using a time series and spectral analysis in conjunction with determination of tremor sources. During tremor episodes, the durations of bursts were about 5 min, while the intervals between the beginning of a burst and the onset of the next one were from 15 to about 17 min. The tremor sources were located beneath the crater south rim at a depth of about 1.2 km, where low frequency events were also located. The dominant frequencies of tremors were 3 to 5 Hz, similar to low frequency events. The relationship between the characteristics of the tremor and rainfall and tidal effects implies the involvement of a hydrothermal system under the crater. On the basis of all these results and similarity to a geyser, we propose a conceptual model to interpret this tremor mechanism.

Keywords: intermittent volcanic tremor , Miyakejima, geyser

Evaluation of Recent Activity at Miyakejima and Increase of Volcanic Gas Discharge in May 2016

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At Miyakejima, the volcanic activity has gradually declined in since the 2000 eruption, and no eruption occurred after January 22, 2013. At the same time, the volcanic gas (sulfur dioxide) emission rate which was beyond 10,000 tons per day at peak also decreases, and now decreased to near the detection limit after June, 2016. The thermal activity in the vicinity of the main fumaroles, in the summit crater, shows a tendency to decrease in recent years, and the geothermal areas seems to be narrow from September 2016 onwards.
On the other hand, focus on recent activities, volcanic earthquakes in the shallow location beneath the summit crater occurred steadily, though it's relatively rare. In addition, according to GNSS observation, the relatively long baseline was growing since around 2006, suggesting that magma accumulation in the deep area continues. Also with the short baseline, shrinkage fluctuation since 2000 has passed through the stagnation from around 2013, and has started to be growing in the beginning of 2016.
Under such circumstances, volcanic tremor accompanied by crustal deformation occurred in February and May 2016, and a temporary increase in volcanic gas discharge amount was observed after this phenomenon. Especially the event in May 2016 showed a more obvious change than the other. Some fluctuations in southeast to southward sedimentation were observed by the inclinometer, and the amount of volcanic gas released, which was less than 100 tons per day before the volcanic tremor, increased to 1,200 tons. The volcanic tremor and tilt can be separated in two states. Estimated pressure source by Mogi model, can be explain the contraction source at a somewhat deep position was predominant at first, next then the inflation source just under the crater was increased. And the position of the source estimated using the amplitude ratio (Ogiso, 2015) was consistent with the position of the shallow inflation source.

Keywords: Miyakejima, volcano deformation, volcanic gas

Topographic change of the sea floor after the 2013-2015 eruption of Nishinoshima

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Nishinoshima is an insular volcano consisting of basalt and andesite located on the volcanic front of the Izu-Ogasawara arc. The first historic eruption occurred in 1973-1974, forming Nishinoshima Shin-to which was connected to the pre-historic Nishinoshima island later. After about 40 year quite period, on November 20, 2013, the eruption activity resumed in the sea to the southeast of Nishinoshima, shifting from a severe phreatomagmatic eruption to a Strombolian eruption (magma eruption). After the Vulcanian eruption on November 17, 2015, no eruptive activity has been observed. The 2013-2015 eruption event is characterized by the expansion of the area of the island due to extensive lava flow which lasted for two years. As a result, the area of Nishinoshima as a whole became about 2.68 km^2 from about 0.22 km^2 before the activity.
Since the restart of the eruption in November 2013, the Japan Coast Guard has conducted the three cruises for bathymetric survey in 2015 and 2016, as well as monthly-basis airborne observations in cooperation with Tokyo Institute of Technology.
We will present the result of bathymetric surveys around Nishinoshima.

Keywords: Nishinoshima volcano, Bathymetric survey, eruption

Temporal change of sea water composition around Nisinoshima Island accompanying the volcanic activity of Nishinoshima

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Nishinoshima, one of the active insular volcanoes on Izu-Mariana arc, restarted its eruptive activity on November 20, 2013 after 40 years dormancy. A small island was newly appeared at SSE offshore of original Nishinoshima on that day and first lava flowed out from the top of the new island on November 22. Effusion of huge amount of lava continued for two years and original Nishinoshima was merged into the huge amount of new lava flow.

The Japan Coast Guard conducted several investigations around Nishinoshima by survey vessel “Shoyo” and unmanned survey vehicle (USV) “Manbo II” from June 24 to July 7, 2015 and by survey vessel “Shoyo” from May 4 to May 6, 2016, and October 25 to November 3, 2016. Seawater sampling in 2015 was carried out at 21sites 200-875m away from the coast by USV “Manbo II” due to the navigational warning to ships within a radius of 4 km from the new crater of Nishinoshima, while that in 2016 was performed at 8sites by survey vessel “Shoyo” owing to shrinking of the warning area. Measurement of pH and dissolved CO_2 was performed on the survey vessel in the same day. Determination of fluoride, chloride and sulfate was carried out at Kusatsu-Shirane Volcano Observatory.

In a term of investigation in 2015, the volcanic activity of Nishinoshima was very active with lava flow and intermittent strombolian eruption. After December 21, 2015 any eruptive activity hasn’t been observed.

There are no remarkable azimuthal dependence of variation in pH and the concentration of F, Cl and SO_4 of the seawater samples collected in 2015 and 2016. The pH values of seawater samples collected in 2015 were mostly about 8.0 and significantly lower than pH of reference seawater. On the other hand, those of all seawater samples collected in 2016 is about the same value as pH of reference point. This suggests that influence by hydrothermal water appeared in the wide area around Nishinoshima in 2015 and that the influence in 2016 was reduced.

Fluoride concentration of seawater samples collected by 2015 survey was comparable with that of reference sample in 2015, whereas that of seawater samples in 2016 was slightly higher than that of reference sample in 2016. Chloride concentration of seawater samples in 2015 was lower than that of reference sample collected in 2015, whereas that of seawater samples in 2016 was almost same as that of reference sample in 2016. Sulfate concentration of seawater samples in 2015 was higher than that of reference sample collected in 2015, whereas that of seawater samples in2016 was almost same as that of reference sample in 2016. These results indicate that the F/Cl molar ratio of seawater samples in 2015 was higher than that of reference sample in 2015 and that the Cl/SO_4 molar ratio of seawater samples in 2015 was determinately lower than that of reference sample in 2015. The F/Cl molar ratio of seawater samples in 2016 was higher than that of reference sample in 2016 and Cl/SO_4 molar ratio of seawater samples in 2016 was comparable with that of reference sample in 2016. It was inferred from these results that huge amount of thermal water discharged from the volcanic edifice was affected by high temperature volcanic gas. While the influence of high temperature volcanic gas to the thermal water was lessened in

2016. Discolored water generated by reaction between hydrothermal water and seawater is often distributed around volcanic islands and submarine volcanoes. Around Nishinoshima Island, discolored water has been observed all the time of investigation by Japan Coast Guard. Greenish-yellow discolored water was distributed around Nishinoshima in 2015 and bluish-white discolored water was distributed in 2016 according to repeated observation by Japan Coast Guard. The change in the color of discolored water around the island indicates the decline of the hydrothermal activity around Nishinoshima Island.

Keywords: Volcanic islands and submarine volcanoes, Nishinoshima volcano, Discolored water

Cross-correlation analysis of infrasound and seismic signal during the phreatic eruption at Hakone in 2015

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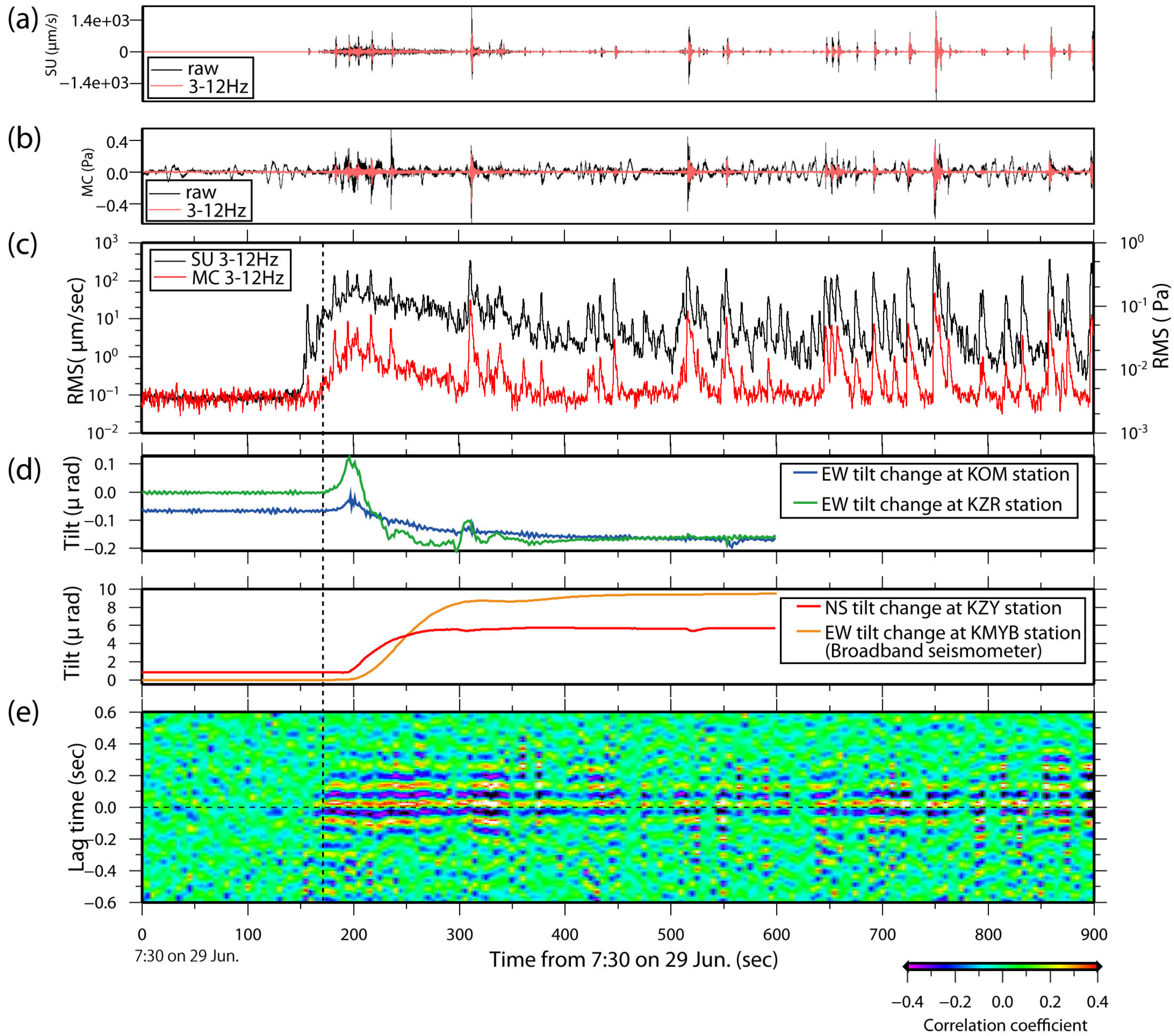
The activity of volcanic tectonic earthquakes in Hakone volcano gradually increased from the end of April, 2015, and small phreatic eruption was observed at Owakidani geothermal region from 29 June to 1 July in this year (Mannen et al., 2015). At the morning of 29 June (at 7:33), abrupt tilt changes of approximately 10 micro radian were detected during two minutes by using tilt meters and broadband seismometers installed around Owakidani geothermal region (Honda et al., 2015). Honda et al. (2015) concluded that these tilt changes could be explained by assuming a shallow open crack source oriented in the NW-SE direction, and they interpreted that hydrothermal fluid of 100,000 m^3 intruded into the region above sea level during the tilt changes. Mannen et al. (2015) reported that volcanic mud flow and ash fall were observed at about 11 and 12 o'clock on 29 June, respectively. However, due to poor visibility around Owakidani region during the eruption, we could not obtain detailed temporal sequence of eruptive activity. In the present study, we conducted a cross-correlation analysis of infrasound and seismic signal to clarify the eruptive activity. Ichihara et al. (2012) demonstrated that infrasonic signals could be identified from a wind noise by using a cross-correlation function of signals from a microphone and a collocated seismometer. We used the waveform record obtained by the microphone and the short-period velocity seismometer at Owakidani station that is located 500m away from the craters. We applied a 3-12 Hz band-pass filter to the infrasonic and UD component seismic signals, and calculated a normalized cross-correlation function of the filtered records, using a 5-s sliding time window. According to Ichihara et al. (2012), significant infrasonic signal can be identified as a pattern of correlation function: the highest peak of correlation function, the negative peak and its node is located around $tau=1/(4f_0)$, $tau=-1/(4f_0)$ and at $tau=0$, respectively, where *tau* is defined as the delay time of seismic and infrasonic signals, and f_0 is the characteristic frequency of infrasonic signal. As a result, we identified the pattern of correlation function in the period from 7:32 to around 10:30 on 29 June, 2015. The appearance time of this correlation pattern is almost coincident with the onset time of the abrupt tilt changes. This result suggests that the emission of volcanic material, such as volcanic gas, started almost simultaneously with the tilt changes, and the infrasonic waves accompanied by the emission generated the ground motion in the immediate area of Owakidani station.

Figure 1 Ground velocity and acoustic signals during the abrupt tilt change on June 29, 2015. (a and b) The raw and the band-passed signals of the vertical component of a seismometer (SU) and a microphone (MC) at OWD station are shown, respectively. (c) RMS amplitudes of the band-passed signals. (d) Examples of tilt records. (e) Normalized cross correlation function of the band-passed seismic and infrasonic signals.

Keywords: phreatic eruption, infrasonic wave


(a)
SU (μm/s)
1.4e+03
0
−1.4e+03
raw
3-12Hz
(b)
MC (Pa)
0.4
0.0
−0.4
raw
3-12Hz
(c)
RMS(μm/sec)
SU 3-12Hz
MC 3-12Hz
RMS (Pa)
(d)
Tilt (μ rad)
EW tilt change at KOM station
EW tilt change at KZR station
Tilt (μ rad)
NS tilt change at KZY station
EW tilt change at KMYB station
(Broadband seismometer)
(e)
Lag time (sec)
0
100
200
300
400
500
600
700
800
900
7:30 on 29 Jun.
Time from 7:30 on 29 Jun. (sec)
Correlation coefficient

Influence of volcanic activity in river floor sediment chemical composition around Hakone volcano

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Introduction: More than 100 active volcanoes are distributed in the Japanese archipelago. One of the definitions of active volcanoes is the eruption history from the past 10,000 years ago. There is no historical eruption history, and there are active volcanoes which currently have no fumarolic activity. Even in such an active volcano, there is a possibility of eruption in the future. In considering volcanic disaster prevention, it is important to predict what kind of activities the quiet active volcano will have in the future. Volcanic activity to occur in the future is highly likely to resemble the volcanic activity that occurred in the past. Even in volcanoes where fumarolic activity is not present, identifying the location of past fumarolic activity is useful for predicting future volcanic activity. River floor sediments represent the elemental concentration of the crust surface layer of the upstream area and have been used to create geochemical maps. In active volcanoes, traces of the influence of fumarolic activity that existed in the past may be left in riverbed sediments. In this study, we will take up Hakone volcano where fumarolic activity exists and investigate whether there is influence on Hayakawa mainstream and tributary flow stream sediments flowing around.
Experiment and Operation method: Samples were taken at 19 locations in the main stream and tributary of Hayakawa flowing around Hakone volcano. We gathered approximately 1 kg of river floor sediment with shovels and after having been dried, We put it out for a sieve and got an fine grain (0.30-0.85mm) and coarse grain (0.85-1.7mm). Next, using a magnet, a magnetic substance such as magnetite was removed from the sieved sample, and then ultrasonic cleaning was performed with pure water. This was pulverized in an agate mortar and dissolved using 0.15 mL of a 6 M $HClO_4$ solution and 0.30 mL of a 25 M HF solution. This solution was further allowed to stand at 120 C. for 6 hours and at 170 C. for 6 hours, heated at 200 C. until dry up and allowed to cool. Finally, the sample was dissolved with 5.00 mL of 0.5 M HNO_3 solution, and 0.5 M HNO_3 solution was further added to the total volume of 25 mL to prepare a sample stock solution. This stock solution was suitably diluted and analyzed by ICP-MS (Thermo Science, iCAP Q).
Results and Discussion: For Hayakawa main stream samples, the concentrations of Sc and V are higher compared to the young crust upper chemical composition in the Japanese archipelago (Togashi et al., 2000), which was matched by the characteristics of volcanic ash excelled areas (mainly East Japan). High concentration of As was detected at the point where the river which flows through the submontane of Mount Hakone and Hayakawa river. It is reported that the As concentration is high in a hot spring that springs off at the central cone of Mount Hakone (Kanagawa Prefecture Onsen geology research center HP). The high concentration As of the river floor sediments discovered this time is thought to be the influence of the volcanic activity of Hakone volcano.
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Keywords: Hakone volcano, Geochemical map, Elemental composition

2015-16 year’ s active of Niigata-Yakeyama volcano -seismic activity, volcanic deformation and plume data-

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Niigata-Yakeyama volcano is a small stratovolcano located in the western part of Niigata Prefecture, Japan. Last magmatic eruption occurred in 1773. Recently, Niigata-Yakeyama repeatedly erupt small phreatic eruptions. Japan Meteorological Agency (JMA) has been monitoring the volcanic activity of Niigata-Yakeyama. In 2015-2016, the activity of Niigata-Yakeyama became active. In this paper, we report the seismic activity, ground deformation plume data observed by JMA.

The height of volcanic plume became high since 2015 summer. Ash fall was observed by on-board observation on April and May 2016 (Oikawa et al., 2017, JPGU). By using the plume-rise method, we estimated the heat radiation rate. As a result, it was revealed that the heat radiation rate at Niigata-Yakeyama was increased from May 2016.
The volcano-seismic activity was increased since 2015. The number of volcanic earthquakes rapidly increased from May 1 to 4. The maximum number of volcanic earthquakes per day was 25 on May 1. After that, the number of volcanic earthquakes gradually decreased.
The volcanic deformation was observed by tilt meters and GNSS. The baseline length between Udana and Maruyamajiri extended from January to August, 2016. SAR Interferometry analysis by using ALOS-2/PALSAR-2 data also detected the ground deformation considered as the inflation of Niigata-Yakeyama (Kamata et al., 2016, VSJ). These volcanic deformation data was explained by the pressure source located at the depth of 4-5 kilometers below the summit area of Niigata-Yakeyama volcano and with the volume expansion of 4.9-5.7 $x10^6$ m^3.

These observation data were considered to indicate the intrusion of magma and the activation of hydrothermal activity at shallow part of Niigata-Yakeyama. JMA expanded the observation network for volcanic activity at Niigata-Yakeyama volcano. Two video cameras and one broadband seismometer were installed. JMA continues to monitor Niigata-Yakeyama volcano.

Keywords: Niigata-Yakeyama, seismic activity, volcanic deformation, plume

On the fumarolic activities of Niigata-Yakeyama in early Showa era, and the review of 1949 eruption.

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Niigata-Yakeyama is an active volcano located at southwestern of Niigata Prefecture. The past activities of Niigata-Yakeyama were investigated by Hayatsu(2008). A moderate magmatic eruption occurred in 1773, accompanying pyroclastic-flows. During the 20th century small phreatic explosions occurred in 1983, 1997, and 1998. As of December 2016, fumarolic activities were found to exit on the summit.
At the end of 2015, the fumarolic activities were observed to be high level, the heights of steam plumes were observed to be higher than previously. A small ash emission occurred in April, May, July 2016, accompanying slight ash fall near the summit.
After Kunii(1950), the fumarolic activities existed in about 1894,1917, and 1918. A new fumarole was generated in 1927, but there were no reports of fumarolic activities after 1927, until the 1949 eruption occurred.
Japan Meteorological Agency observes or monitors the volcano activities or eruptions and publishes the data of volcanic activities as bulletins since Meiji era. Historically, such as Syowa era, disclosure or publications of them were not sufficient.
Niigata Local Meteorological Office has old observation data or documents on Niigata-Yakeyama. These data include the reports conducted by Kami-Hayakawa village in 1930s, and the investigation reports of the eruption that occurred in 1949. According to the documents, local inhabitants at about 10km from the summit crater heard the sounds of plume ejection, the sounds were like a jet engine or an automobile’s engine. The inhabitants also sensed the smell of volcanic gas in 1932. The villager or climbers found a hot geyser near the summit in July 1932. Local inhabitants saw ‘White Line’ on the slopes of Niigata-Yakeyama, actually that was a hot water flow. The same phenomenon occurred in the 1949 eruption, the 1974 eruption and in July 2016.
We re-inspected the documents of the eruption occurred in February 1949, and we estimated the amount of ash fall based on the data of ash fall depth. We compared those two eruptions, the 1949 eruption and the 1974 eruption, estimated which eruption was larger or more explosive.
In the 1949 eruption, an explosive sound or air shock were felt by the inhabitants at 16km from the summit crater. By contrast, in the 1974 eruption, an explosive sound was felt at 4 to 6km from the summit crater.
The 1949 crater was located at the east-side slope of the mountain, the 1974 crater was located at the west-side slope of the mountain, therefore the difference of crater location might cause the difference of explosive sound propagation.
The depth of ash fall of the 1949 eruption were about 30 millimeters at SEKI hot spring, TSUBAME hot spring, 21 millimeters along JR Shin-etsu Line, and 11 millimeters at Shinano-Daira station.
We estimated the amount of ash fall of the 1949 eruption, the weight of the total ash fall was at least about 2.0×10^6 tons. After Chihara(1975), the total amount of ash that was ejected of the 1974 eruption was 6.5×10^5 tons. We consider that the amount of ash fall of the 1949 eruption will be as same as that of 1974 eruption.
Seismic activity remains above background levels. According to GNSS measurements, the dilatation of the baseline that traverses the summit has declined since summer of 2016. We need to monitor volcanic activities continuously.

Keywords: Niigata-Yakeyama, 1949 eruption

High-frequency tremor with frequency transition at Mt. Asama, Japan

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There are few studies on volcanic tremor in a higher frequency range than 10 Hz. As an example, Hotovec et al. (2013) reported volcanic tremor with frequency transition from low to high (> 20 Hz) frequency ranges during eruption of Mt. Redoubt in 2009. In this study, we report high-frequency volcanic tremor at Mt. Asama with low-to-high frequency transition in a range of 20˜30 Hz, on the basis of V-net data provided by NIED. We find the tremor 161 times at Takamine station and 36 times at Onioshidashi station during a period from January 1, 2011, to July 15, 2016. Function fitting on the frequency transition in spectrograms of vertical motion reveals that a logarithm form is the best. We investigate temporal distribution of the tremor occurrences and find that the tremor frequently occurred in the morning from November to April. This point implies a possible relation between the tremor occurrences and snow coverage on Mt. Asama.

Keywords: Volcanic tremor, High-frequency tremor, Mt. Asama, Snow coverage

Relation between long-period seismic signals and SO_2 emission at Asama volcano from October 2003 to January 2017

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Vulcanian eruptions had started on September 1st 2004, lasting until December 2004 at Mt. Asama. After that, several small and minor eruptions occurred in August 2008, from February to May 2009, and in June 2015. We compile long-period seismic data and SO_2 data from October 2003 to January 2017, and consider the relation between long-period seismic signals and volcanic gas emission. We categorize long-period seismic signals into three group; the first category is a very long-period pulse (VLP) excited by a sudden gas emission from northen part of the conduite [Takeo et al., 2016]. The second category is a long-period rebound waveform (LP earthquake), and the third category is long-period tremor characterized by pointed tips and sawtooth waveform. We propose a mathematical model succeeding in simulating the oscillations resembling with these second and third categories signals. Before June 2004, VLP activity was synchronized with the seismicity, but it had gradually decreased toward the eruption in spite of increment of the seismicity. At this turning point, LP earthquakes and nonlinear tremors occurred in cluster. Based on the mathematical model, LP earthquake and the nonlinear tremor could be actualized by a blockage of the conduit, resulting the decline of VLP activity due to shielding of gas emission and the increment of seismicity due to stress accumulation in and around the conduit [Takeo et al., 2016]. The minor eruptions in 2008 and 2015 were preceded by rapid activation of VLP activity and/or increment of SO_2 emission, and large VLPs preceded these minor eruptions by two to four minutes. Based on the VLP activity and SO_2 emission data, the minor eruptions in 2008 and 2015 were interpreted as large-scale gas emission events. SO_2 emissions had been kept in high level from November 2008 to February 2009 in spite of low VLP activity, but this relation had turned over from April to August 2009. After the 2015 eruption, SO_2 emission level often had been kept more than 1000 ton/day by the end of November 2015. After that, low SO_2 emission had been continued until December 2016 in spite of relative high level of VLP activity compared with that before the 2015 minor eruption. In this period, VLP activity seems to increase gradually, followed by a rapid increment of SO_2 emission in January 2017. The variability of correlation between SO_2 emission and VLP activity suggests an existence of multi outgassing pathways in the shallow part of the conduit.

Keywords: Asama volcano, Long-period earthquake, Volcanic gas

Mechanism of Stromoblian eruption at Aso volcano in terms of a model of slug ascending and bursting

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At Aso volcano, frequent Strombolian eruptions occurred in late April 2015, at a rate of 20-30 events every hour. Though Strombolian eruptions have been observed since 1930s at Aso volcano, the mechanism of generation of seismo-acoustic signals accompanying Strombolian eruption and the physical model of the eruptive process have not yet been revealed. In this study, we estimated the process of Strombolian eruption using the records of seismo-acoustic sensors deployed around the crater. Each eruptions was accompanied with characteristic signals of low- and high-frequency seismic waves and of infrasound waves. Dominant period of low-frequency seismic signal is 12 s, which is shorter than that of long-period tremor (15 s; Kaneshima et al., 1996). However, particle motion of this signal indicates similar source region as that of the tremor, 1-2 km depth beneath the crater. At the depth a crack-like conduit whose upper end connects to a much narrow path has been identified (Yamamoto et al., 1999; Yamamoto et al., 2008). At the conjunction portion at the roof of this crack, a slug can be made by a foam collapse (Jaupart & Vergniolle, 1988) and migrates upward to the crater. Mechanisms of very-long-period and long-period seismic signals accompanying Strombolian eruptions are considered as an association with a motion of a slug inside the magma conduit, especially structural discontinuous area (e.g. Aster et al., 2003). Based on this idea, we assume that low-frequency seismic signal observed at Aso volcano can be attributed to resonance of the crack when a slug enters the narrow conduit from the crack. Considering a result of explosion depth estimation, 200 m beneath the crater floor, inferred from time difference of seismo-acoustic signals, ascending speed of the slug is estimated as ~40 m/s. This value agrees well with the estimate at Stromboli volcano, 10-70 m/s (Harris & Ripepe, 2007). The dominant frequency of infrasound signal at the eruption is ~0.5 Hz. This band of air-pressure perturbations is also observed when no eruptions occur, but its amplitude is one order smaller than that at eruption. This means that the 0.5 Hz signal may be defined by the length of the conduit above the magma-air interface where explosions occur. This concept seems to be reasonable from a result of laboratory experiments modeling a bubble bursting (Kobayashi et al., 2010) in which a frequency of excited airwave at the bursting is the same as that of fundamental mode of the air column resonance above the interface. Here, assuming that a depth of magma surface (explosion depth) and the air sound velocity inside the conduit above the magma surface are 200 m and 400 m/s respectively, the frequency of the fundamental mode of air column resonance (one side open and the other side closed) can be calculated as ~0.5 Hz. This is precisely the same value of our observed frequency. Based on these facts, we suppose that release of internal pressure of the slug starts at a slug bursting at the magma surface, and forces amplitude of the air column resonance to increase. At the Strombolian eruption at Aso, we could also observe high frequency infrasound signal (> 10 Hz; 4-s duration). Though this signal is superimposed on the 0.5 Hz signal, it is clearly delayed ~0.3 s from the arrival of 0.5 Hz band. This high-frequency signal is probably related to continuous strong gas escaping that can break magma membrane surrounding the slug into small fragments. However, an exact reason why it takes 0.3-s delay from the start of slug rupturing is not yet clear.

Keywords: Aso volcano, Strombolian eruption

A study of the temporal change in oscillatory characteristics of Long-period tremor at Aso Volcano, Japan

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Low-frequency earthquakes and long-period events observed at active volcanoes are considered to be generated by the motion of volcanic fluid like magma and volcanic gases, and the elucidation of these signals and their temporal change are one of the critical keys to understand the dynamics of the volcanic system. At Aso volcano, various kinds of volcanic signals with broad frequency contents have been observed since the pioneering work by Sassa in 1930s. One of these signals is long-period tremor (LPT) with a dominant period of around 15 s, which are intermittently emitted from the volcano regardless of the surface activity. The characteristics of the LPTs are fairly short duration of only a few cycles and multiple spectral peaks at 15 s, 7 s, and so on. Our observations using broadband seismometers so far have revealed that LPTs are a kind of resonance oscillation of a crack-like conduit beneath the crater. Because the resonance characteristics of a fluid-filled crack are strongly controlled by the physical properties of the fluid inside the conduit and the geometry of the conduit, in this study, we analyze the temporal variation of oscillatory characteristics of Long-period tremor from 1994 to the present.

In this study, we first examine the temporal variation of dominant periods of LPTs (fundamental mode of around 15 s and first overtone of around 7 s) using the continuous data recorded at broadband seismic stations close to the active crater. The result shows clear temporal change in the dominant periods of LPTs in 2003-2005 and 2014-2015. These two time periods corresponds to the periods in which small phreatic and phereatic/magmatic-hydrothermal eruptions occurred. As to the temporal variation in 2003-2005, as already reported by Ikeda (2005) and Yamamoto (2013), the periods of the fundamental mode and the first overtone show correlated temporal change, and it can be interpreted as compositional and/or thermal change of hydrothermal fluids. On the other hand, in 2014-2015, the period of first overtone is almost constant at around 8 s, while that of the fundamental mode shows relatively large temporal fluctuations between 16 s and 12 s. Such a trend is rather difficult to explain, if we consider the resonance oscillation of a flat fluid-filled crack.

In this study, we therefore examine the oscillatory characteristics of a fluid-filled crack having linearly varying thickness. As a result, it becomes clear that the dispersion of the boundary wave along the fluid-filled crack becomes weaker and thus the ratio between resonance periods of the fundamental mode and the first overtone becomes smaller than the case of a flat crack having constant thickness. This behavior can be understood by considering that the effective thickness of the crack depends on the wavelength of each resonant mode. Based on these results, the different temporal variation of dominant periods of the two resonant modes can be interpreted by depth-dependent thickness of the crack-like conduit which caused by pressurization and/or intrusion of magma at deeper portion of the conduit. Our result suggests that the long-term trend in the state of volcanic fluid systems beneath active volcanoes may be monitored by seismological means.

Keywords: Volcanic earthquake, Hydrothermal system, Boundary wave

Long period pulse preceding the explosive eruption of Aso volcano, October, 2016

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At 01:40, October 8, 2016, an explosive eruption occurred at the Nakadake first crater of Aso volcano. Type of the eruption is regarded as phreatomagmatic eruption because glassy particles are included in the ejecta (JMA,2016). Two long period pulses(LPP) were observed 6 minutes and 2 minutes before the eruption, which we called LPP1, LPP2, respectively.
In this work, we analyzed the broadband seismograms in order to unveil the source mechanism of the LPPs since it is thought that the mechanism contains the information of the preparatory process of the explosive eruption.
We used the broadband seismic data at 8 stations around the Nakadake first crater. The distances from the crater to each station are 0.3~2.3km.
Based on the particle motions at each station, we estimated the source location of LPPs by waveform semblance method (Kawakatsu et al. 2000). It was estimated that the source of LPP1 is located at 270m south-west of the crater (32.88237N, 131.08416E), 0m above sea level, and the source of LPP2 is located at 300m south-southwest of the crater (32.88237N, 131.08416E), 120m above sea level. They are about 100m apart from the LPP source location estimated in Kawakatsu et al.(2000). In addition, compared with the location of the crack-like conduit under the crater(Yamamoto et al. 1999), LPP sources are in or close to the crack. Moreover, we calculated RMS amplitude of 10~30s band-pass filtered vertical seismogram. As a result, the amplitude distribution is very similar to long period tremor(LPT) that was observed in Yamamoto et al.(1999). Thus, it is inferred that same conduit behavior, a resonance of the crack-like conduit, can be a source model of LPP. Furthermore, our result shows that the source moved upward between two events, however, it is under investigation whether this move is significant or not.
Then, we calculated Fourier spectrum of LPPs with time width of 150 seconds. Spectrum peaks of LPP1 are 12~20s(unclear), 7.5s, 5s, and those of LPP2 are 17s, 10s, 6s. Period of LPP2 is longer than LPP1. It is thought that LPP period depends on the conduit length, or sound velocity of the fluid in the conduit because LPP is interpreted as resonance of the conduit(Kawakatsu et al. 2000). Thus, the conduit condition likely changed between two events, which occurred within 4 minutes just 2 minutes before the explosion.

Keywords: Aso volcano, explosive eruption, long period pulse

Chemical composition of minerals and melt inclusions in Kusasenrigahama pumices from Aso volcano, Kyushu, Japan -Comparison with Aso-4-

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In this study, we analyzed Kusasenrigahama pumice to compare with Aso-4 volcanic product about whole rock chemical composition, chemical composition of minerals and melt inclusion, and water concentration in melt inclusion. Kusasenrigahama pumice was erupted from Kusasenrigahama pumice cone about thirty thousand years ago, which is in the west of Aso central cones. We collected pumices from four volcanic sand layers in the outcrops at the west −southwest of Kusasenrigahama pumice cone. The four layers were distinguished by pumice size and volcanic sand’ s color: A, B, C, and D, in ascending order. Kusasenrigahama pumice contains plagioclase, orthopyroxene, clinopyroxene, and opaque as minerals.

Results of analysis show that mineral composition of Kusasenrigahama pumice is homogeneous, scale of volcanic activity depends on water concentration, and magma chamber under the Kusasenrigahama pumice cone is lower water concentration and higher temperature, compared with Aso-4.

(a) Uppermost and lowermost layer of Kusasenrigahama pumice shows nearly the same chemical composition of constituent minerals (plagioclase; An# = 64 ~68, clinopyroxene; Mg# = 75 ~ 77, orthopyroxene; Mg# = 72 ~ 74). Clinopyroxene and orthopyroxene is almost the same composition between Kusasenrigahama pumice and Aso-4. On the other hand, plagioclase composition of Kusasenrigahama pumice is different with that of Aso-4.

(b) Water concentration in MI of lowermost layer (A) is higher than that of uppermost layer (D). Compared with Aso-4, MI of Kusasenrigahama pumice contains less water.

(c) Clinopyroxene and liquid thermobarometers shows temperature and pressure, 897 ±45 ℃, 1.8 kbar respectively. When this pressure is applied, plagioclase and liquid thermometer shows temperature, 888 ±37 ℃. These temperature is higher than temperature of Aso-4 (810 ~ 850 ℃).

Keywords: Aso volcano, Melt inclusion, Kusasenrigahama pumice

Volatile content of magmas of the 2014, 1989, and 1979 eruptions of Naka-dake, Aso volcano based on melt inclusion analyses.

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Volatile content of magma is one of important controlling factors for magma ascent and volcanic eruption. Melt-inclusion analysis is a powerful method for estimating volatile content of melt in magma before eruption. At Naka-dake, Aso volcano, volcanic activity increased September 2013, and minor eruptions occurred January 2014. Since then, eruptions had intermittently occurred up to October 2016, together with intense volcanic gas emission. In this study, we carried out petrological observation and chemical analyses of melt inclusions of the scoria of the 2014, 1989 and 1979 eruptions of Naka-dake to know the eruption and degassing processes.
Whole-rock composition of the scoria was determined by a wave-dispersive X-ray fluorescence analysis (XRF). Observation of the cross sections, chemical analyses of the minerals, determination of major elements and sulfur contents of melt inclusions and groundmass were carried out by electron probe micro analyzer (EPMA). Water and CO_2 contents of the melt inclusions and matrix glass were determined by secondary ion mass spectrometry (SIMS). Analytical errors of the volatile analyses were ±0.2 wt.% for H_2O, ±0.0028 wt.% for CO_2, ±0.007 wt.% for S (Saito et al., 2010).
Five scoria of the 26-27 November 2014 eruptions have andesite composition (SiO_2 =54 wt.% and K_2O=2.0 wt.%) and are identical to those of scoria of the November 1979 eruptions (Ono and Watanabe, 1985). The scoria contained 22-31 vol % plagioclase phenocrysts, 5-13 vol % clinopyroxene phenocrysts, a few vol % of olivine and FeTi-oxide phenocrysts. The plagioclase phenocrysts have core of An_{62-91} and rim of An_{60-79}. The clinopyroxene phenocrysts have core of $Wo_{36-41}En_{43-47}Fs_{15-20}$ and rim of $Wo_{36-40}En_{42-46}Fs_{17-19}$. The olivine phenocrysts have core of Fo_{65-68} and rim of Fo_{59-68}. Two-pyroxene thermometry (Lindsley, 1983) applied to an orthopyroxene inclusion contained by a clinopyroxene phenocryst gave magma temperature of 1113±51ºC. Melt inclusions in plagioclases, clinopyroxenes and olivines have andesite composition (SiO_2=58-62 wt.%, K_2O=3.1-4.7 wt.%), that is similar to chemical composition of the groundmass. The melt inclusions have volatile content of 0.6-0.8 wt.% H_2O, 0.003-0.017wt.% CO_2 and 0.008-0.036 wt.% S. The variation in CO_2 and S contents of the melt inclusions is not related to the K_2O content, suggesting magma degassing with pressure decrease. Gas saturation pressure estimated from the H_2O and CO_2 contents and solubility model (Papale et al., 2006) is 22-78 MPa, corresponding to 1-3km depths. Combining the melt-inclusion analysis with observation of volcanic gas, we can estimate degassed-magma volume. The amount of degassed magma (1-3 km^3) was estimated, based on the sulfur contents of the melt inclusions and SO_2 flux during a period of January 2014 to December 2016 (1000-3000 t/d; JMA, 2016), assuming that only SO_2 existing as sulfur component in the volcanic gas and magma density of 2700 kg/m^3.
Melt inclusions in plagioclases, clinopyroxenes and olivines from the 1979 and 1989 eruptions have andesite composition (SiO_2=57-62 wt.% and K_2O=2.3-3.8 wt.% for 1979 eruptions, SiO_2=57-63 wt.% and K_2O=3.2-5.4wt.% for 1989 eruptions). The melt inclusions of the 1979 eruptions have volatile content of 0.3-1.6 wt.% H_2O, 0.007-0.034wt.% CO_2 and 0.010-0.035wt.% S. The melt inclusions of the 1989 eruptions have 0.3-0.6 wt.% H_2O, 0.003-0.009wt.% CO_2 and 0.008-0.031wt.% S. Major elements and volatile contents of melt inclusions of the 2014 eruptions are similar to those of the 1979 and 1989 eruptions. The similarity of chemical composition of whole-rocks and melt inclusions among these eruptions suggest petrologic characteristics and volatile content of the magma in the magma chamber had not changed from 1979 to 2014.

Keywords: Aso volcano, Naka-dake, magma, melt inclusion, volatile, degassing

The injection of high-sulfur basaltic magma into shallower reservoir beneath Aso

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We analyzed the major elements of bulk rock, melt inclusion (MI) of minerals and host minerals and volatiles (H_2O, Cl, S) of MI of Holocene volcanic products from the northwestern part of Aso central cones to obtain the information of magma reservoir.
In this study, we used scoria samples of Ojodake and Kamikomezuka, which erupted in Holocene. Bulk rock composition of samples were determined by X-ray fluorescence (XRF) at Kitakyushu Museum of Natural History and Human History. Sample preparation techniques and analytical procedures are based on those of Mori and Mashima (2005). Major elements and volatiles (S, Cl) of MIs, host minerals and glasses were determined by SEM-EDS at Kumamoto university and EPMA at Earthquake Research Institute, University of Tokyo. Water concentrations in MIs were measured by Fourier transform infrared (FT-IR) micro-reflectance spectroscopy at ERI, university of Tokyo (Yasuda, 2011, 2014).
MIs of the phenocrysts shows two compositionally different types. One is mafic (SiO_2 46.7-57.5 wt. %) and high-S (<4000 ppm), and the other is felsic (SiO_2 52.3-59.8 wt. %) and low-S (<1000 ppm). Mafic group is hosted in olivine (Ol), felsic group are hosted in plagioclase (Pl), clinopyroxene (Cpx) and orthopyroxne (Opx). Matrix grass has intermediary composition of them. Volatiles of matrix glass were almost degassed. The S contents of Ol hosted MI tend to decrease with decreasing hosted-Ol Mg#. About felsic group, measured H_2O contents in melt inclusions from Ojodake are highest (<3 wt. %); Kamikomezuka inclusions have lower H_2O values (<1 wt. %). Those of mafic group were mostly below detection (Max 0.8 wt. %). Some phenocrysts of Pl and Cpx exhibits reverse zoning at the rim. Pl phenocrysts were divided into two groups, an Ab-rich core (An 60-65) and an An-rich core (An 85-87). Opx phenocrysts typically have a reaction rim of Cpx and Ol.
High volatile/K_2O ratios of MI hosted Ol indicates that it has high volatile contents initially. High-S content mafic magma was found by melt inclusion studies beneath the frontal volcanoes in central and northeastern Japan (Yamaguchi et al., 2003; Yamaguchi, 2010). It has become clear that volatiles in arc magma are enriched by subduction (Wallace, 2005; Zellmer et al., 2015). In general, the high S contents of basaltic melt require oxygen fugacity (fO_2) greater than FMQ+1 (Wallace, 2005; Jugo et al., 2005; Jugo, 2010). And there is some correlation of S content in the melt with Fe content, fO_2 and temperature (Wallace & Carmichael, 1992). The compositional gap of S contents between mafic and felsic group may reflects the degree of differentiation.
In considering the low-SiO_2, high-Mg# and volatiles in MIs and disequilibrium texture of felsic group phenocrysts, it is concluded that mafic group derived from deep-reservoir. These observations are explained by the injection of high-S basaltic magma into shallower reservoir.

Keywords: Aso, EPMA, FT-IR, melt inclusion, sulfur, water content

Estimation of subsurface velocity structure beneath Kirishima volcanoes inferred from ambient seismic noise tomography

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Shinmoe-dake, one of Kirishima volcanoes, experienced magmatic eruptions in 2011. The analysis of ground deformation shows that the pressure source locates 5 km to the northwest of the Shinmoe-dake summit at a depth of 8 km, which implies the existence of a magma reservoir. We are trying to resolve the better image by a seismic exploration technique toward ensuring its existence and deriving precise crustal structure.
The technique we employed is the seismic wave interferometry, which extract the seismic wave propagation between two seismic stations by taking a cross correlation of random wavefields, such as the ambient seismic noise or the seismic coda wave, recorded at two stations. The cross correlations of random wavefields recorded at two receivers can be represented as if the source is at one receiver and the recorder is at the other. This technique is suitable for exploring local structure since the extracted wave is sensitive to the internal structure between two stations.
We inferred the crustal phase velocity anomaly using three-component records of the ambient seismic noise recorded by seismic array between April 2011 and December 2013. Rayleigh and Love waves are extracted by taking cross correlations (Rayleigh waves from Z-Z and R-R components of cross correlation functions, and Love waves from T-T component). We derived reference dispersion curves of Rayleigh and Love waves, respectively, using all pairs of stations, then measured a phase velocity anomaly against the reference for each pair in four frequency ranges (from 0.1 to 0.2 Hz, from 0.2 to 0.4 Hz, from 0.3 to 0.6 Hz and from 0.4 to 0.8 Hz) for Rayleigh wave and in two frequency ranges (from 0.3 to 0.6 Hz and from 0.4 to 0.8 Hz) for Love wave.
The inferred Rayleigh wave phase velocity structure shows that the inside of Kirishima volcanic region and nearby region have the characteristics of low velocity against the outside for all frequency ranges. In particular, the Rayleigh wave phase velocity structure in a frequency range from 0.1 to 0.2 Hz (corresponding to around 5-10 km depth) is characterized by two remarkable low velocity regions: one lies at almost same location of the pressure source of the ground deformation, and the other is located beneath the region from Shinmoe-dake to Ohata-ike. Similar characteristics are found from 0.2 to 0.4 Hz (around 3km depth) and from 0.3 to 0.6 Hz (around 2 km depth) for Rayleigh wave. They are also detected in a frequency range from 0.3 to 0.6 Hz for Love wave. The Love and Rayleigh wave velocity structures from 0.4 to 0.8Hz (around 1km depth) show low velocity characteristics right beneath the entire volcanic region.

Keywords: Kirishima volcanoes, surface wave velocity structure, ambient seismic noise

One-dimensional resistivity structure and the relocated hypocenter distribution of Iwo-yama, Kirishima Volcanoes

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Iwo-yama is the youngest volcano in the Kirishima volcanic group. Around Iwo-yama and Karakuni-dake, shallow (depth $<$ 2km) tectonic earthquakes have increased since December 2013, and volcanic tremors have occasionally occurred since July 2015 (Japan Meteorological Agency, volcanic activity commentary document). Furthermore, the fumarolic gases appeared in December 2015 for the first time in 12 years. The leveling survey detected the ground uplift during June to December 2015, and its pressure source was estimated at a depth of 700 m, 150 m east of the crater (Matsushima et al.,2015). Therefore, it is reasonable to be concerned about the occurrence of hydrothermal eruptions.
In order to investigate the mechanism of these volcanic activities and possibility of future eruptions, we conducted broadband (0.005 to 3000s) magnetotelluric (MT) measurements around the Iwo-yama in April 2016. We recorded two components of electric fields at 20 observation sites and five components of electric and magnetic fields at 7 observation sites. One-dimensional inversion revealed that the shallow earthquakes occur beneath a shallow electric conductive layer, which is interpreted as a hydrothermal altered clay dominant zone. The pressure source by the leveling survey corresponds to the bottom of the conductive layer. These spatial relationships suggest that the supply of high temperature fluids has increased beneath Iwo-yama, and causes the increase in pore pressure beneath clay layer, resulting in the increase of earthquakes and ground inflation. In this presentation, we will further estimate the precise depth of earthquakes, and will investigate its relation to the shallow conductive layer.

Vertical ground deformation of Ioyama, Kirishima volcanoes measured by precise leveling survey (during Mar. 2012 - Nov. 2016)

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Ioyama is an active volcano located in Ebino kogen volcanic area, Kirishima Volcanoes, southern Kyusyu, is activated from December 2015. We conducted the precise leveling survey in the Ebinokogen volcanic are from March 2012 to November 2016. The purpose of the survey is to reveal the vertical deformation and pressure source. We measured in December 2015, February, March, June, November 2016. Inflation of the Ioyama was detected from we initiated this observation to March 2016. Subsequently, the ground subsidence from around June 2016. However, uplift is detected around the Ioyama again in November 2016.

From the surveyed leveling data in November 2016, the vertical displacements indicate the ground uplift at all bench marks. In this study, the reference bench mark is BM1120 at the western flank of Ioyama. The amount of maximum uplift is about 17.2 mm near the summit referred to BM1120 in November 2016. We estimated pressure source models based on the vertical deformation. We supposed the presence of an inflation spherical source as Mogi’ s model, the depth has been inferred about 700 m. The lower limit of low resistivity layer assumed to be the clay layter is estimated in this depth (Aizawa et al., 2013). Accordingly, the inflation source by using precise leveling survey is located under the impermeable clay layer. In addition, the increase of pressure source volume since June 2015 is detected 4.8×10^4 m^3 in November 2016.

Keywords: Ioyama, precise leveling survey, vertical deformation

Distribution and occurrence of the pyroclastic flow deposit of the 2011 eruption of Shinmoedake, Kirishima volcano group, Southern Kyushu, Japan

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We investigated occurrence of the pyroclastic flow deposit of the 2011 Shinmoedake eruption about 5 years later. During a subplinian eruption, very small pyroclastic flows descended down on the south-western slope up to 800 m long, with 30 m wide. The volume of the deposit is estimated to be about 20,000 m^3. No splintered stumps were found on the course of the flow, so it suggests that the speed of the flow was slow. The pyroclastic flow was estimated to be generated by a small-scale partial collapse of the subplinian eruption column.

Keywords: Kirishima volcano group, Shinmoedake, 2011 eruption, pyroclastic flow, sub-plinian

Infrasonic activity of Sakurajima volcano in 2015, inferred from an infrasound array analysis.

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In Sakurajima volcano, explosive eruptions have occurred frequently at around 1000 times at a year since 2009, and continuous geological investigations, such as infrasound, seismicity, tilt, and Global Navigation Satellite System (GNSS) have been used to monitor the volcanic activities (Iguchi et al., 2013). On August 15, 2015, the magma intrusion event different from usual state occurred. It is reported that the frequency of the explosion decreased across that period. In this study, we report the outline of the infrasound activity of Sakurajima from January to December 2015 recorded by an infrasound array.

In October 2014, we installed the infrasound array (TKT) in the Kagoshima University research forest at Takatoge-Kogen (11 km southeast of the Sakurajima Showa crater, altitude of 540 m). Four stations of array were installed; three stations were placed at each vertex of the triangle whose aperture of 200 m, and the other at the center. Three of them are installed with sensor (differential pressure gauge) and digitizer, power is supplied by the solar panel. Power of the other station is supplied by commercial power and we also installed the sensor, digitizer and data aggregation-transmission system. The data were recorded at a sampling rate of 50 Hz and transmitted by fiber optic cables. The central station and the other stations are connected by fiber optic cables passed through a protective tube and buried in the 20-30 cm underground to avoid the influence of thunder and animals. However, in the vicinity of a rough ground situation covered with thick leaves, cable exposure due to rain fall accompanying the outflow of the ground surface cannot be avoided and it became impossible to communicate in about one and a half years after installation. Although there are data missing due to power of PC failure intermittently, data is acquired continuously from January to December 2015. In this time, we analyzed the date in that period.

Median filter processing and trend removal were performed on the obtained data, and then a 0.3-5 Hz band pass filter was applied. First, based on the Sakurajima eruption record table by the Japan Meteorological Agency (JMA), records in TKT 15 minutes before and after the JMA' s explosion record time was cut out, and a semblance analysis was continuously performed while varying the time by 5 s at an analysis length of 10 s to event detection and estimate the direction of infrasound arrival. After that, with respect to each station, a cross correlation function assuming that the delay time when signal comes from the Showa crater is calculated every 1 s, a moving average of 5 min is applied, and from January to December 2015 to estimate the infrasound activity of Sakurajima.

636 explosions occurred during the TKT' s operation among the 737 explosion records in 2015 by JMA, and all infrasound data were recorded in TKT. Of the explosion recorded in TKT, even for the one with the smallest infrasound amplitude in Seto (1.3 Pa), we confirmed that for the all signals predominantly arrived from Sakurajima direction (300°N). In the case of a large amplitude explosion, it was also confirmed that reflected waves from the topography around TKT arrived, as pointed out by Yokoo et al., (2014). The reflection wave arrived mainly from 180°N to 130°N. These are reflected waves from Mt. Yokodake and Mt. Takakuma , sounth and southeast to TKT station. In addition, the reflected waves from the 80°N direction are relatively weak, and these are considered to be due to the direction of the Kushira river, the altitude is lower than around.

Next, we analyzed the energy of infrasound continuously coming from Sakurajima, using the cross-correlation function. In order to distinguish the increase in the local noise, we also calculated the power of infrasound simultaneously arriving from the direction of the Kushira River (80°N) as a reference. As a result, also between the reported explosion-eruption, it is confirmed that week infrasound activities occur continuously or intermittently. In the future, we will clarify what kind of surface activity corresponds when weak infrasound recorded at TKT, in combination with infrasound data and movies in the vicinity of Showa crater. Also, we would like to consider how much it affects the eruption cycle and scale.

Keywords: Volcanic erupiton, Sakurajima Showa Crater, Infrasound array analysis

Time variations between shock wave and a subsequent formation of bright cloud at Vulcanian eruptions of Showa crater, Sakurajima volcano, Japan

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To investigate mechanism of Vulcanian eruption, we analyzed eruption movies (30 frame/s) of Showa crater, Sakurajima volcano, Japan. 88 eruptions during December 2011 to May 2015, which accompanied variable infrasound wave, were selected for an analysis. First, we investigated the relationship between an intensity of infrasound and a speed of volcanic plume at the crater. Maximum amplitude of infrasound data observed at Seto and Arimura stations (JMA) shows positive correlations with the ejection speeds of volcanic plume. This result thought to be consistent with preceding vulcanian eruption models (Turcotte et al., 1990; Woods, 1995; Alatorre-Ibargüengoitia et al., 2010) which shows ejection speeds increase if overpressure in the conduit increase. Second, we investigated the time lag between an onset of visible shock wave and a subsequent formation of bright (white) cloud close to the crater. The obtained time lag varies from 0.2 to 1.1 s with maximum frequency 0.6s, and may be related with the variation of size and/or the location of "gas pocket" (e.g., Ishihara, 1985; Iguchi et al., 2008) formed under the crater just before the explosion at Sakurajima.

Real-time analyses of continuous relative gravity data collected at Sakurajima Volcano

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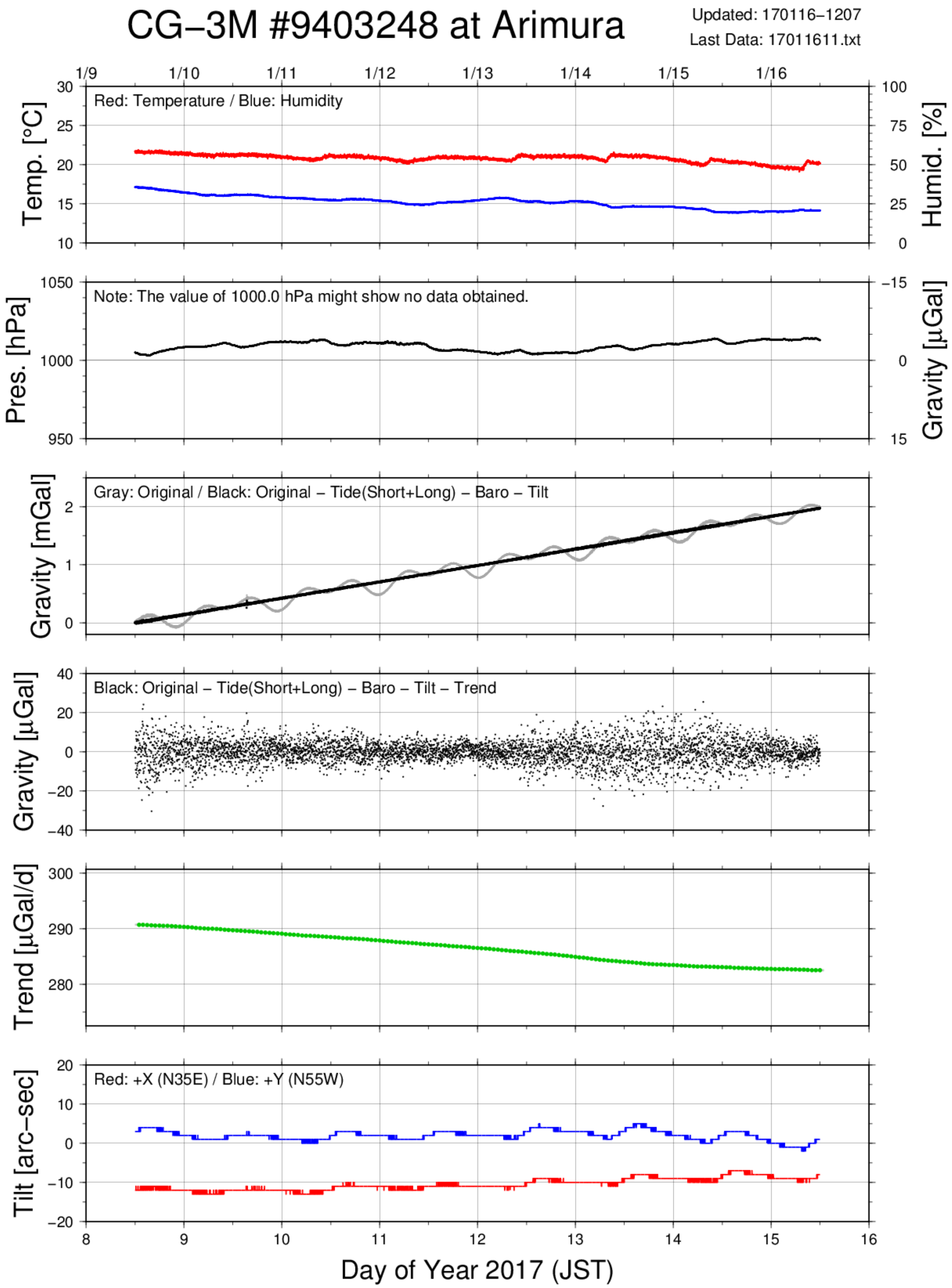
Continuous gravity observation is one of the most powerful methods to monitor mass redistributions in volcanoes. In Japanese volcanoes, absolute gravimeters have detected gravity changes of less than 10 microGal originating from volcanism, with those time period of more than a few days (e.g., Kazama et al., JGR, 2015). However, absolute gravimetry cannot precisely detect short-period (< one day) gravity changes due to the low signal-to-noise ratio in the high frequency domain. On the other hand, broadband volcanic phenomena have been monitored by other geodetic observations at many active volcanoes (e.g., Iguchi et al., JVGR, 2008). If the short-period volcanic gravity signals can be detected by continuous gravity observations other than absolute gravimerty, volcanic phenomena will be minutely discussed in terms of mass redistributions.

Kazama et al. (Kazan, 2016) thus installed a CG-3M relative gravimeter at Arimura in the southern part of Sakurajima Volcano, and started collecting continuous gravity data at one-minute interval. They succeeded in detecting a rapid gravity decrease of -5.86 microGal during the rapid inflation event on 15 August 2015; this gravity change is smaller than the typical observation error of relative gravimeters (~10 microGal), but the high-frequency measurements of relative gravity contributed to the detection of the small gravity change in the case of Sakurajima Volcano. They also pointed out that the gravity change was consistent with one of the dike intrusion models provided by Geospatial Information Authority of Japan (2015) if the density value of 0.97 +/- 0.37 g/cm3 was assumed, which implies the drastic foaming of the intruded magma.

We utilized their method to construct the real-time analysis system of continuous relative gravity data collected at Sakurajima Volcano. The following procedures are automatically executed every hour in this system. (1) Continuous data of relative gravity and air pressure are uploaded from logging laptops to a server. (2) The gravity/pressure data is downloaded from the server to a computer installed in Kyoto University. (3) Three effects are corrected from the raw gravity data: tidal gravity change, gravity change due to air pressure change, and artificial gravity change due to instrumental tilts. (4) Instrumental drift is removed, by fitting a linear function to the corrected gravity data of the past seven days. (5) Graphs of the collected/analyzed data are drawn and uploaded to a web server.

We show one of the graphs drawn by this system at noon on 16 January 2017. This graph displays the seven-day variations in air pressure, raw gravity, corrected gravity, drift rate, and instrumental tilts. If significant mass redistributions occurred associated with volcanism, rapid time variations could be included in the panels of corrected gravity and drift rate, and/or instrumental tilts might change due to volcanic inflations, as detected on 15 August 2015 (Kazama et al., Kazan, 2016). We are going to maintain this analysis system in order to monitor mass redistributions associated with volcanism in Sakurajima Volcano instantaneously.

Keywords: Sakurajima Volcano, volcanism, gravity change, relative gravimeter, mass distribution


CG–3M #9403248 at Arimura
Updated: 170116–1207
Last Data: 17011611.txt
1/9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
Red: Temperature / Blue: Humidity
Temp. [°C]
Humid. [%]
Note: The value of 1000.0 hPa might show no data obtained.
Pres. [hPa]
Gravity [µGal]
Gray: Original / Black: Original – Tide(Short+Long) – Baro – Tilt
Gravity [mGal]
Black: Original – Tide(Short+Long) – Baro – Tilt – Trend
Gravity [µGal]
Trend [µGal/d]
Red: +X (N35E) / Blue: +Y (N55W)
Tilt [arc–sec]
Day of Year 2017 (JST)

Structural state of plagioclases within volcanic ash from Sakurajima volcano: Preliminary investigation of monitoring volcanic activity by constituent mineral

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Sakurajima volcano, one of the most active volcanoes in Japan, has seen an increase in the magnitude and frequency of activity over the past decade. This activity has been studied by many geophysicists, with most focusing on seismic waves and crustal movement that occurred nearby. Many geochemists have approached igneous activity from the viewpoint of whole-rock chemical analysis and mineral composition analysis of direct products, such as volcanic ash and lapilli, but few studies have applied crystallography in analysis. The goals of this study are to obtain basic data for understanding magmatism just under the Sakurajima volcano and to construct a new and efficient method for investigating and monitoring volcanic activity, focusing on the crystal structure of constituent minerals within the volcanic ash. Toward this second goal, the structural state of plagioclases within volcanic ash erupted from Sakurajima volcano was preliminarily investigated. Samples were collected for about 27 months starting in May 2013 at Higashi-Sakurajima Junior High School, which is located about 4 km southwest of Minami-dake crater. It is known that $B(2\theta_{(1-11)} - 2\theta_{(-201)})$ versus $\Gamma(2\theta_{(131)} + 2\theta_{(220)} - 4\theta_{(1-31)})$ for plagioclases, as determined from X-ray powder diffraction data, distinguishes among structural states and gives a rough estimate of plagioclase composition. The B/Γ plot measured for the plagioclases in the volcanic ash suggests a gradual change in degree of order in the crystal structure during this period. Further results from long-term analysis of volcanic ash are expected to clarify aspects of the volcanic activity of Sakurajima volcano.

Keywords: Sakurajima, volcanic ash, plagioclase, X-ray powedr diffraction, structural state

Development of Unmanned Ash-fall Detection System, Part2

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We developed revised unmanned facility to detect pyroclastic fall deposit since the 2011 eruption of Kirishima Shinmoedake and Sakurajima volcanoes. Our goal is to develop a method to obtain the semi-real time information of pyroclastic fall phenomena to contribute eruption forecasting and to advance high precision reconstruction of the sequence of the past eruptions from their deposits. Our revised system is named "Futteru-kai (kai means ash in Japanese)" consists of ultrasonic distance probe, load cell, and network camera supplied by 12 volts battery with solar panel. Electric equipment are packed within waterproof vessel to protect sulfuric gas invasion. Testing was performed at Sakurajima Arimura from January 2015 to March 2016. Load cell shows large variance depending on temperature with negative correlation. Ultrasonic distance probe showed stable value slightly diminishing which suggests deposition of pyroclastic fall deposits on measuring surface. Minor outlying results several times larger than actual value or over-range were also observed. Two centimeters of diminishing distance between the probe and the surface is well coincided with actual measured distance. We are now preparing to dispatch next volcano where major ash fall eruption is expected.

Keywords: monitoring, eruption, ash fall, ultrasonic, Sakurajima

Pyroclastic flow deposit of the 2015 Kuchinoerabujima Volcano

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Explosive phreatomagmatic eruption on May 29, 2015 of Kuchinoerabujima Volcano produced pyroclastic density currents (PDC) in all directions from the summit crater of Shindake. The PDC reached to the coastal line ~2 km from the summit crater. The PDC is characterized with the distribution of thin deposit. The thick block and ash flow deposit distributed in a limited area within the vicinity of the crater. Nevertheless the thin deposit, most of the trees in the area of the PDC were broken and overturned, suggesting a strong flow with high velocity. No remarkable wildfire in the PDC area suggested that the temperature of the deposit was not reached the ignition temperature of the wood. However, the facts that all leafs on the trees within the peripheral PDC area were killed by the thermal damage and one person involved in the PDC got burn injury suggest that the temperature within the PDC was fatal.
We surveyed the distribution and sequence of the PDC deposit and thermal and mechanical damages by the PDC within the area of PDC. The thermal damage was remarkable in the upper part of the trees which were directly exposed to the PDC. The thermal damage on the trees were limited within the area of PDC. No thermal damage was recognized in the area where was covered by the ash fall from the PDC. The nylon items in the PDC deposit were partially melted. The thickness of the deposit at the end of the PDC area in Mukaehama was less than 5 cm. The deposit shows remarkable normal-grading from lapilli and very-coarse sand at the base to very-fine sand at the top. At the base of the deposit, lapilli ~1.5 cm in diameter were found. Many plant fragments in the deposit tell the strong flow which destroyed the forest along its pass. These observations indicate that the deposit was formed by a short and single-pulse PDC with high velocity. This is consistent with the visual observations by some monitoring cameras.

Keywords: volcano, eruption, pyroclastic flow , Kuchinoerabujima Volcano, phreatomagmatic eruption

Enhancement of volcanic observation system of JMA near the volcanic crater

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1. Introduction

Based on lessons learnt from the eruption of Ontake Volcano on 27 September 2016, the Coordinating Committee for Prediction of Volcanic Eruptions discussed enhanced monitoring systems for active volcanoes and proposed urgent recommendations on November 2014; a final report from the Committee was also published on 26 March 2015. Responding to these recommendations and report, Japan Meteorological Agency (JMA) decided to install various instruments near volcanic craters and increase the number of observation facilities to continuously monitor more volcanoes. Furthermore, JMA started to develop methods for earlier detection of precursory phenomena of phreatic eruption. In this report, we will show the outline of our efforts to enhance the monitoring systems and some observational results.

2. Enhancement of observation systems near volcanic craters

In general, intensities of preceding activities of phreatic eruptions are weak and appear only in the vicinity of the crater. In order to monitor and detect small precursors, JMA decided to install following instruments near the craters of 48 active volcanoes in Japan: (i) infrared and visible light cameras to monitor thermal activities and change of fumaroles, (ii) broad-band seismometers and tiltmeters to detect low-Frequency seismic signals caused by the movements of volcanic gas or hydrothermal activities. Since such instruments are installed in high places around craters, they are often exposed to severe weather conditions, such as strong winds, heavy snow and lightning. In order to keep stable operations, we took care of the robustness of the systems.

3. Development of methods for earlier detection of precursory signature of phreatic eruptions

Changes of volcanic gas composition and geomagnetic total intensity were often observed prior to past phreatic eruptions. JMA, therefore, decided to observe components of volcanic gas (4 volcanoes) and geomagnetic total intensities (6 volcanoes, including scheduled) near the craters of volcanoes and start to develop methods for earlier detection of precursory signature of phreatic eruptions. Since JMA does not have any experience to conduct continuous volcanic gas observations, we installed instruments with the cooperation of Meteorological Research Institute (MRI) and National Institute of Advanced Industrial Science and Technology (AIST).

4. Examples of observed data

We observed a volcanic tremor accompanied by a long-period seismic signal and small tilt change around Ontake Volcano on 27 September 2016. We also recorded the thermal image at the moment of the eruption of Aso Volcano on 8 October 2016. JMA is going to investigate techniques for accurate evaluation of volcanic activities by using data observed by these newly installed instruments. The observation data will become available for research institutes; it aims to encourage effective data utilizations and extensive developments in volcanological studies. It is expected that such developments will give positive feedback to JMA's volcanic activity evaluation process.

Keywords: phreatic eruption, tiltmeter, broadband seismometer, infrared and visible light cameras

Ground Deformation around Domestic Active Volcanoes detected by D-InSAR of ALOS-2/PALSAR-2 (2014 -2016)

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Monitoring of volcanic activity by observing ground deformation is one of useful means to understand signs of eruption such as migration and accumulation of magma and volcanic fluids. Japan Meteorological Agency (JMA) monitors volcanic activity by tiltmeter, light wave distance measuring and GNSS around volcanoes. However, there are some problems only using these ground-based observation methods. Observable ground deformation is restricted to point information such as the tilt at the observation point and relative position between observation points. Also, it is difficult to install and maintain observation device due to bad transportation infrastructure at remote mountainous volcanoes, heavy snow and keep-out area by eruptions. It is important to grasp surface ground deformation around volcanoes using not only ground-based observation but also satellite data like SAR (Synthetic Aperture Rader).
PALSAR-2, an L-band SAR on ALOS-2, is useful to understand ground surface state, and its interferometric coherence is highly effective for the ground deformation observation. PALSAR-2 has higher efficiency than ALOS/PALSAR. It is short repeat observation cycle (14days) and has a high resolution sensor and can realize right-side and left-side observation. Therefore, we can use higher resolution and more frequently data. Under the cooperation of Meteorological Research Institute (MRI), JMA conducts D-InSAR using PALSAR-2 data around domestic active volcanoes and analysis results are used for the volcanic activity evaluation and judging eruption alert level such as the activation of Hakone volcano in 2015, the eruption of Kuchinoerabujima, the magma intrusion in Sakurajima (Secretariat of Satellite Analysis Group, Coordinating Committee for Prediction of Volcanic Eruption, 2016). In this presentation, we mainly report on the analysis results of the long-term pair (2014 to 2016.) around the domestic active volcanoes. The results were reported to Coordinating Committee for Prediction of Volcanic Eruption as well as the results of 2014 to 2015 (Ando, et al., 2016).
Some of PALSAR-2 data were prepared by the Japan Aerospace Exploration Agency (JAXA) via Coordinating Committee for the Prediction of Volcanic Eruption (CCPVE) as part of the project ‘ALOS-2 Domestic Demonstration on Disaster Management Application’ of the Volcano Working Group. Also, we used some of PALSAR-2 data that are shared within PALSAR Interferometry Consortium to Study our Evolving Land surface (PIXEL). PALSAR-2 data belongs to JAXA. We would like to thank Dr.Ozawa (NIED) for the use of his RINC software. In the process of the InSAR, we used Digital Ellipsoidal Height Model (DEHM) based on ‘the digital elevation map 10m-mesh’ provided by GSI, and Generic Mapping Tools (P.Wessel and W.H.F.Smith, 1999) to prepare illustrations.

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

Locally distributed crustal deformation in potential areas of phreatic eruptions detected by InSAR analyses

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Phreatic eruptions may be related to transient pressure changes in subsurface regions of hydrothermal systems attributing a heating of shallow aquifers from magma. It means that crustal deformation presumably proceeds with the pressure increase under the ground, which can be a kind of precursor if it would be detected. One of the most difficult points is that as the eruption size becomes smaller, the precursor signal should be more local, suggesting that it is rather hard to identify the anomaly using conventional ground-based observation tools. An effective proactive monitoring method for phreatic eruptions is desired, and one of the tools to overcome the drawbacks is SAR observation.

Hakone Owaku-dani: Inflational signal has been detected in a local area with a diameter of ~200 m by InSAR analysis, associated with the volcanic activity that started from the end of April, 2015. The distribution of the crustal deformation has a concentric pattern at the initial stage, but the location of the maximum displacement shifted southwestward although the spatial size has not changed. The small eruption occurred in the end of June at the location where the largest displacement was observed. The most important point for this event is that locally distributed crustal deformation has been successfully detected prior to the eruption, and the eruption did occur at the anomalous area. In Hakone volcano, there has been several remarkable volcanic activities since 2001. In this context, it is vital to investigate the crustal deformation at these activities to better understand the relationship between an eruption and such local deformation. Applying InSAR analysis to ALOS data for the 2008 activity, no significant signal can be identified in the Owaku-dani area. In 2001 and 2015, fumarole activities has increased outstandingly, while no significant anomaly of fumarolic activity can be identified in other activities. It is probably suggested that pressure increase associated with heat supply from the depth has not proceeded in the subsurface in the 2008 activity. I will report InSAR analysis results for other past activities.

Tateyama Midagahara (Jigoku-dani): Jigoku-dani area is known as an active geothermal area with fumarole and boiling water activity. In the past few years, geothermal activity on the ground has become more visibe with burning and flow out of sulfur in 2010 and increased temperatures of fumarole. Applying InSAR time series analysis to ALOS data, I detected locally distributed inflational deformation in the Jigoku-dani geothermal area. The deformation speed is estimated to be at about 4cm/yr at maximum. The deformation area is spatially consistent with the area where active fumarole and boiling water are seen on the ground. I additionally applied InSAR analyses to ALOS-2 data to investigate recent crustal deformation. The result shows that there appears no significant deformation in these two years. The geothermal activity is still in high-level, but the state is relatively stable in time. These SAR observation results probably suggest that no significant pressure change has proceeded in the geothermal system at shallow.

Anomalies observed on the ground surface such as fumarolic activity is thought to be directly related with the state change of the geothermal system. It seems that there is a good correlation between the SAR-derived local crustal deformation and the geothermal anomaly on the ground. It is suggested that the InSAR-derived deformation data can be a kind of indicators exploiting the state of pressure under the ground, and can extract some physical parameters related to phreatic eruptions. In this presentation, in addition to above-mentioned cases, I will show some local ground inflational signals observed in geothermal areas where eruptions have not occurred as yet.

Acknowledgements: ALOS-2 data were provided under a cooperative contract with JAXA (Japan Aerospace Exploration Agency). The ownership of ALOS-2 data belongs to JAXA. This study was supported by JSPS KAKENHI Grant Numbers JP16K17797 and JP25350494.

Keywords: phreatic eruption, InSAR, local crustal deformation

Estimation of viscosity of erupting magma from lava flow morphology

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Eruption types of volcanoes depend on magma viscosity. For example, in the case of magma with much volatiles, viscous magma causes Plinian eruption, and conversely magma with low viscosity causes Hawaiian eruption which forms lava fountain. Thus, in studying volcanic eruptions, it is meaningful to investigate viscosity of erupting magma.
Viscosity of lava flow varies according to various factors like temperature (Minakami et al., 1951) and petrologic compositions (Shaw, 1972). In this study, we focus on lava flow morphology formed by volcanic eruptions, and aim to establish a method for estimating viscosity and to calculate viscosity of erupting lava flow from various volcanoes. The merit of this morphological method is that it requires no direct observation data such as flow rate or temperature, so it can apply to various lava flows erupted in the past.

The method of calculating viscosity from morphological parameters of lava flow such as thickness and width is presented by Stevenson et al. (1994). Firstly, we used lava flow simulation offered by Earthquake Research Institute (Yasuda et al., 2013) to evaluate the utility of this method. This simulation uses the method presented by Ishihara et al. (1990). We determined morphological parameters from the simulation results, calculated viscosity using Stevenson’ s formula, and then compared with original value calculated from erupting temperature using Minakami’ s formula. As a result, values obtained from Stevenson’ s method showed different distribution from the original values’ . Also, it proved that this method cannot calculate because of error when assumed viscosity was too high.
We used a new method to estimate viscosity in order to solve the above problem. This time, we adopted aspect ratio which can be obtained by dividing lava flow thickness by the square root of its area size. We calculated aspect ratio from the simulation result, and then derived a relation among the ratio, gradient of the ground, and original viscosity calculated from erupting temperature. We also applied this relation to real lava flow topography and ascertained its usefulness. Although the verification is not enough, this method of aspect ratio is expected to be applied to various places because it can obtain significant results regardless of lava flow characteristic or gradient of the ground.

Keywords: lava flow, magma, viscosity, aspect ratio

Numerical study on the onset of explosion earthquakes

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Vulcanian eruption is characterized by sudden ejection of volcanic fragments, excitation of shock wave, and explosion earthquake. Analysis of explosion earthquakes provides us important features to understand the source dynamics of Vulcanian eruptions. A number of previous studies reported that the polarity of the onset of explosion earthquakes is compressional at all stations (e.g., Minakami, 1960). The focal depth of explosion earthquakes is usually estimated at several km beneath the active vent (e.g., Imai, 1980). Observed waveforms of explosion earthquakes are explained by volume change (e.g., Tameguri et al., 2002) or vertical single force (e.g., Ohminato et al., 2006). However, the source mechanism obtained from inverse analysis of observed waveforms represents macroscopic force system at the source region. It is still challenging to infer the dynamics in the volcanic conduit from seismic analysis.

Magma fragmentation and ejection of volcanic material accompanying Vulcanian eruptions are often modeled by the shock tube theory (e.g., Woods , 1998). To obtain fundamental characteristics of explosion earthquakes, we examine displacement field induced by the shock tube problem in a vertical elastic pipe. We adopt OpenFOAM to calculate fluid-solid interaction (FSI). Since the original version of FSI solver in OpenFOAM(foam-extend 3.0) can handle incompressible flow only, we modify the solver to calculate the interaction between compressible flow and elastic media. For simplicity, the fluid in the elastic pipe is assumed as ideal gas. The elastic pipe has 20 m radius and 4 km length. The elastic media surrounding the pipe is set for 4 km from the pipe. The depth of a diaphragm of shock tube is assumed at the focal depth of explosion earthquakes at some volcanoes. We set the pressure difference at the diaphragm in the pipe referring estimated overpressure of Vulcanian eruptions by previous studies. In the pipe, high pressure region is assumed beneath the low pressure region as the initial condition.

The result of our numerical simulation shows that compressional displacement field is induced in the elastic media at the depth where the pressure in the pipe has increased. Contrary, dilatational displacement field is seen at the depth where the pressure in the pipe has decreased. The elastic wave propagates from fluid-solid boundary at the depth of the diaphragm. The polarity of the onset of elastic wave has a nodal plane about 30° upward from the horizontal plane. The elastic wave propagating above the nodal plane show the compressional polarity. Therefore, the displacement waveforms at the surface of elastic media near the pipe show the compressional onset. On the other hand, since the nodal plane across the ground surface, displacement waveforms at far side from the pipe have the dilatational onset. The pressure change in the pipe below the diaphragm (pressure decreasing) is almost twice of that above the diaphragm (pressure increasing). Therefore, the angle of the nodal plane of the polarity may reflect the pressure change in the pipe.

We compare the result of numerical simulation and features of explosion earthquakes at Lokon-Empung volcano (Yamada et al., 2016). Yamada et al. (2016) reported that the focal depth of explosion earthquakes is about 1 km beneath the active vent. The polarity of the onset of explosion earthquakes are compressional at all stations, ranging 1.7-6.9 km from the active vent. Our numerical simulation shows that the compressional onset is seen at the region near the pipe (< 1.5 km), assuming the diaphragm as 1 km beneath the surface. Contrary, the compressional onset cannot be seen at far side region (> 1.5 km) from the pipe. Therefore, it is suggested that additional source process has to be considered to reproduce the initial compressional wave at all stations. The ejection of volcanic fragments accompanying Vulcanian eruptions lasts only about several tens of seconds, Therefore, it is regarded that the fragmentation process of Vulcanian eruptions also has the same range of duration. Since the fluid in the pipe is assumed as ideal gas, the process that terminates the eruption is not considered in our numerical simulation. Taking into account this process will be valuable to examine the entire characteristics of observed waveforms.

Keywords: Vulcanian eruption, shock tube, OpenFOAM

A generalized equation for the resonance frequencies of a fluid-filled crack

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Although a model of the resonance of a rectangular fluid-filled crack (crack model; Chouet, 1986, JGR) is one of the most frequently used source models of long-period (LP) seismic events at volcanoes, there has been no analytical solution for the resonance frequencies. We previously proposed an empirical expression for the resonance frequencies (Maeda and Kumagai, 2013, GRL):
$f_m = (m - 1)a/\{2L_x[1 + 2\varepsilon_m C_x]^{1/2}\}$, (1)
where a is the sound velocity of the fluid, L_x is the crack length along the wave propagation direction, m is the mode number defined such that the wavelength is $2L_x/m$, C_x is the crack stiffness, and ε_m is an empirical constant that depends on the crack aspect ratio χ and oscillation mode m. Although eq. (1) can potentially be used to compute the resonance frequencies easily, the requirement to determine the value of ε_m numerically for each crack aspect ratio and oscillation mode has prevented widespread use of the equation for interpretations of LP events at volcanoes.

In the present study, we examined the theoretical basis for the expression. We assumed that the ratio of the crack wall displacement to the fluid pressure near each crack edge varied as the square root of the distance from the edge. Using this assumption, we showed theoretically that eq. (1) was a good approximation (difference 2%) to another more complete expression:
$f_m = (m - 1)a/(2L_x I_m)$, (2)
$I_m = (1 - 4\gamma/5m)J_m(g_{m0}C_x) + (16\gamma/15m)[1/K_m(g_{m0}C_x) + 1/K_m(g_{m0}C_x)^2]$, (3)
where $J_m(\xi) = (1 + 2\xi)^{1/2}$, $K_m(\xi) = J_m(\xi) + 1$, $\gamma = 0.22$, and
$g_{m0} = (1 - 4\gamma/3m\chi)/(3m - 4\gamma)$ (4)
for $\chi > 4\gamma/m$ and
$g_{m0} = (2/3)(m\chi/4\gamma)^{1/2}/(3m - 4\gamma)$ (5)
for $\chi < 4\gamma/m$. The constant g_{m0} in eqs (4) and (5) is related to ε_m in eq. (1) as $\varepsilon_m = g_{m0}(3m - 4\gamma)/(3m)$.

This theoretical expression (eqs 2-5) is a closed form of a mathematical function of the crack model parameters and oscillation mode number; there are no empirical constants to be determined numerically. The expression thus enabled us to analytically compute the resonance frequencies for arbitrary rectangular cracks, and the results were in good agreement (difference 5%) with numerical solutions. Resonance frequencies of cracks can be very easily predicted using this expression. This predictive ability may enhance our quantitative understanding of the processes that generate LP events at volcanoes.

Keywords: LP event, Resonance, Crack

Analysis of sound generated by the vibration of a bubble film

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Introduction

Bubble sounds have been measured with active degassing at volcanoes and used to estimate the gas flux (Vergniolle and Brandeis, 1996; Johnson et al., 2008; Bouche et al., 2010). The estimation assumes a specific mechanism of generating bubble sounds. However it is challenging to distinguish the specific mechanism from other possible mechanisms in the acoustic data observed at volcanoes. Here we investigate the characteristics of bubble sounds and a sound generating mechanism in laboratory experiments.

Experimental method and observations

It has been reported that bubble sounds differ by fluid rheology. We follow the experiments by Lyons et al. (2013) which used a viscoelastic transparent gel. Bubbles rise in the fluid with coalescence and oscillation, and finally escape from the fluid surface. The sequences are recorded by microphones and a high speed camera.

We find two main processes generating sound: (1) bubble detaching from a nozzle and (2) rising bubble above the fluid surface. In this experimental model, no sound signal is detected with bubble bursting. We focus on the signals generated by (2), because they are clearly distinguished from other signals and noise due to the following particular features.

The features about sound frequency: the sound frequency glides to the higher. The features about sound amplitude: the envelope has a spindle shape with the maximum mostly occurring when about a half to 2/3 of the bubble is on the surface. The amplitude is not always proportional to the radius of a bubble. Sudden damping occurs after the maximum amplitude, which is sometimes caused by drops touching the film of bubble. When the bubble bursts, the amplitude decreases quickly. The signal is very weak when a bubble bursts earlier. The amplitude is significantly large when an oscillation of bubble is excited before it appears on the surface.

Model Calculation

Here we call ‘head’ as the part of bubble on the fluid surface, ‘tail’ as the part below the surface. The bubble behaviors are separated into the three time parts: (A) the head rising, (B) the head absorbing the tail, and (C) the shape being settled.

In the focused process, the sound is generated by vibration of the head. Referring to Verginiolle and Brandeis (1996), who discussed the same mechanism, we formulate the vibration equation of a spherical shell with adding an internal excitation term due to the increase of the head radius. The radial motion the head is converted to the far-field acoustic wave (Blackstock, 2000), of which waveforms are similar to the experimental observation.

Both amplitudes of the radial oscillation of the head and acoustic wave grow when the radius of head is increasing in (A) and (B) and is damped in (C). Then, the spindle-shaped envelope of the signal is reproduced.

Incorporating the head and tail change with the model enables the oscillation to start without an external excitation. When an external excitation is initially given, the amplitude becomes larger without changing the waveform.

The followings are suggested by model. A bubble needs an excitation under the surface to generate a

sufficiently large acoustic signal on the surface.
The controlling factor of the frequency gliding is the ratio between the volume of the head and the tail in (A), the radius of the head in (B), and the film thickness in (C).

Discussion and Future Tasks
We discuss whether we can estimate the bubble volume using the sound of the focused mechanism. The amplitude is not useful because it is significantly affected by the condition of the head of bubble and external excitation. The upward gliding frequency is the feature used to identify this mechanism. The beginning of the frequency change is controlled by the radius of the head so that it is potentially useful to estimate the bubble volume.

Keywords: bubble, sound, volcano

