Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SVC48-01 Room:104 Time:May 19 11:00-11:15

Relationship between volcanic activity and chemical and isotopic compositions of thermal waters in Tokachidake, Japan

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Tokachidake volcano, one of the most active volcanoes in Japan, caused three magmatic eruptions (AD 1926, 1962 and 1988-89) in the 20th century, and the volcanic activities tend to increase recently. In this study, we investigate chemical and isotopic compositions of thermal waters in Tokachidake volcano and discuss the relationship to the volcanic activity.

Bengara hot spring (BHS), Hakuginso hot spring (HHS), Fukiage hot spring (FHS) and Okina hot spring (OHS) are located at the western flank of the volcano, about 3 km from the summit craters. Chemical compositions of BHS, FHS and OHS and those of HHS have been continually investigated since AD 1986 and 1992, respectively. The temperature of thermal waters of BHS, HHS and FHS ranges from 48 to 56 ^{o}C, whereas that of OHS is about 25 ^{o}C. These thermal waters are acidic with the pH ranging from 2.5 to 3.0.

The chemical compositions of these thermal waters show temporal changes. The Cl/SO_4 ratio of these thermal waters was about 0.2 in AD 1986. Since then the Cl/SO_4 ratio had abruptly increased, and the ratio of BHS and FHS was about 2.9 and 3.9, respectively, at the time of the AD 1988-89 eruption. The increase of the ratio had continued until AD 1992, whereas then the ratio had decreased to 0.6 until AD 2010. Temporal change of the chemical compositions of HHS shows nearly the same as that of BHS and FHS, and the ratio had decreased until AD 2010. Since AD 2010, however, temporal change of the ratio of these three thermal waters has changed to constant or weak increase. In addition, these thermal waters have shown obvious increase of the ratio since June 2012, and the ratio reached about 1.0. In contrast, temporal change of the chemical compositions of OHS is clearly distinct with that of other thermal waters, and the ratio have roughly decreased until the present. In all thermal waters, there is no remarkable temporal variation of SO_4^{2-} concentration, and hence we can consider that temporal change of the Cl/SO_4 ratio has been caused by change of Cl^- concentration.

In addition to the chemical compositions, the oxygen and hydrogen isotopic compositions of these thermal waters have been investigated since AD 2011. All samples collected before July 2012 show nearly the same isotopic compositions as meteoric waters, ranging from $d^{18}O$=-13.6 to -12.1 per mil. In contrast, thermal waters of BHS and HHS, which were collected after October 2012, show heavy oxygen isotopic composition compared with meteoric waters, ranging from $d^{18}O$=-10.9 to -9.8 per mil.

The increase of the Cl/SO_4 ratio of thermal waters and shift of the oxygen isotopic composition toward heavier value indicate that supply of volcanic gas into thermal waters has increased. Observations of chemical and isotopic compositions of thermal waters are important for evaluating the future volcanic activity of Tokachidake volcano.

Keywords: Tokachidake volcano, thermal water, stable isotope, chemical composition

SVC48-02 Room:104 Time:May 19 11:15-11:30

Resistivity structure around the Aira caldera

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The Aira caldera is located in southern Kyushu and was formed by the catastrophic eruptions of the Aira volcano approximately 29,000 years ago. Sakurajima is a post-caldera volcano and started to grow in the southwestern part of the caldera after 3,000 years of the Aira eruptions. It repeats explosive eruptions more than eight hundred times per year in recent three years. Since co-eruptive depression of the ground around the Kagoshima Bay was observed after the 1914 eruption of Sakurajima volcano (Omori, 1916), the source of magma supply to Sakurajima is presumed to be located at a depth of 10km beneath the Aira caldera (Mogi, 1958).The objective of this study is to clarify the corresponding electrical resistivity structure to the assumed magma reservoir and to the supply paths to Sakurajima volcano.

We have conducted the magnetotelluric (MT) measurement mainly along two traverse lines in the direction of WNW-ESE crossing the Aira caldera since 2009. The MT data at 39 sites in total, including 16 seafloor sites, were obtained for the last four years. For the seafloor observation, the electromagnetic field was recorded for about two to three weeks with a sampling interval of 8 Hz using several OBEMs (Ocean Bottom Electro-Magnetometers). For the land observation, the MTU-5 systems of Phoenix Geophysics Ltd. were used to measure the EM field with the frequency range of 0.001-320 Hz. We performed a 2-D analysis along two lines across the Aira caldera. The strike direction for 2-D analysis was estimated from the individual impedance data obtained on land by using a decomposition technique (Groom and Bailey, 1989).

As results of the 2-D inversion (Ogawa and Uchida, 1996) applied to the TM-mode data set, a high conductive region of less than 10 ohm-m was found in the southern profile beneath eastern Aira caldera at depths greater than 7-8 km. This conductor appears to extend upward, but it is not clear because of shortage of the higher frequency data obtained by OBEMs. Location of the conductor seen in the resistivity model is roughly in agreement with the location of depression source inferred from the geodetic data (Eto and Nakamura, 1986). This indicates that the conductive zone is possibly the structure relevant to the magma reservoir.

Keywords: magma reservoir, Sakurajima volcano, resistivity structure, Aira caldera, OBEM

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SVC48-03 Room:104 Time:May 19 11:30-11:45

The fourth round of repetitive seismic experiment in Sakurajima Volcano

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Evolution of seismic reflectors beneath Sakurajima Volcano is presented, which is revealed with rounds of seismic experiments after 2008. Sakurajima Volcano is one of the most active volcanoes in Japan. The rounds of seismic experiments have been carried out while the activity on the 1946's crater in the eastern frank rose up after its revival on 2006, after the pilot survey in 2008. A round of seismic experiments includes 14 shot points with charges and 252 temporary stations with a vertical seismometer for seismic reflection survey. The temporary stations were deployed along two lines in the east foot and in the northern frank of the volcano. The evolutions of seismic response are detected in seismic records corresponding to the ray paths passing through the northern to north eastern part of Sakurajima. The migrated sections from the differential seismograms show detailed evolution in the seismic reflector distribution beneath the depth of 4km which can represent magma intrusion. A seismic reflector with negative polarity rose up to the depth of 4km in the north-eastern portion of Sakurajima Volcano where a chimney like structure locates, during 2008 to 2009 while constant inflation of the volcano. Other negative reflectors enhanced and decayed in the deeper part. These movement of seismic reflectors is consistent with geodetic evidence of the magma movement in the period. Therefore such evolution of seismic reflectors can represent intrusion of magma towards the craters. On the other hand, sporadic reflectors with positive polarity appear around the depth of 2km in two sections on the 2009's and the 2011's round which obtained while frequent explosions at the 1946's crater. The depth of the sporadic reflectors are coincident with the bottom depth of the effective part in the explosion models which have been presented by Iguchi(1994) and Tameguri(2004). Therefore the sporadic reflectors in the shallow part can represent a sort of mass deficiency raised by the explosions. We found controlled source seismic monitoring of volcano is feasible. The controlled source seismic monitoring will provide certain advantages in understanding scale and in evaluation of its potential risk in the next phase of current activity. Detail of the experiment 2012 and our method will be presented.

Keywords: Sakurajima Volcano, Subsurface structure, Seismic exploration, Dynamic structure, Magma

SVC48-04 Room:104 Time:May 19 11:45-12:00

Three dimensional resistivity structure of Kirishima volcanoes inferred from anomalous magnetotelluric data

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Broad-band magnetotelluric (MT) measurements were conducted on 2010?2011 around Shinmoe-dake volcano in the Kirishima volcanic group, Japan, where sub-Plinian eruptions took place three times on 26?27 January 2011. Combining with the previous MT data, it is found that the anomalous phase in excess of 90 degree is commonly observed at the northern part of the Kirishima volcanic group. Because the anomalous phase is not explained by 1-D or 2-D structure with isotropic resistivity blocks, 3-D inversions were conducted. By applying the small error bars on anomalous phase, we successfully estimated a 3-D resistivity structure that explains not only the usual data but also the anomalous phase data. The final model shows a eastward inclined and clockwise twisted pillar-like conductor that connects a deep-seated conductive body (at a depth greater than 10 km) to a shallow conductive layer at the central part of Kirishima volcanoes. By using the geophysical and petrological studies of the 2011 sub-Plinian eruptions, we infer that the pillar-like conductor represent the zone of hydrothermal aqueous fluids over 400 C, in which a magma pathway (interconnected melt) is partly and occasionally formed before magmatic eruptions. To the north of the deep conductor, earthquake swarms occurred on 1968?69, suggesting that these earthquakes were caused by volcanic fluids.

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SVC48-05 Room:104 Time:May 19 12:00-12:15

Imaging of the inner structure of a lava dome in Unzen, Japan and a shallow conduit in Stromboli, Italy

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The latest lava dome in Mt. Unzen was formed in the eruption from January 1991 to early 1995 and the activity was calmed down in 1995. The researchers kept to observe the eruption in this period precisely. Some of them proposed the growth model, another person proposed different model from their data. It is significant for the growth model and the landslide prediction to investigate the density structure in the lava dome. The observation of the lava dome density 2D map was performed by using cosmic-ray muon and muon detector in Unzen. The muon detector, nuclear emulsion films which has high position resolution and 0.85m2 effective area, was installed in a natural cave from early December 2010 to the end of March. The developed nuclear emulsion films has been scanned by automated muon readout system.

Stromboli is one of the Aeolian Islands, which is located at a volcanic arc north of Sicily Island Italy. 1.0m2 nuclear emulsion films was installed at the site which is 500m far from active volcanic conduit. After there month exposure, the films were developed and we started to analyze them in the beginning of April 2012. The systematic analysis of efficiency and random noise ratio estimation are performed by taking a pattern match and making a connection of muon tracks between several films. We will report the first results of Unzen and Stromboli results.

Keywords: volcano, imaging, muon radiography, Stromboli, Unzen, lava dome

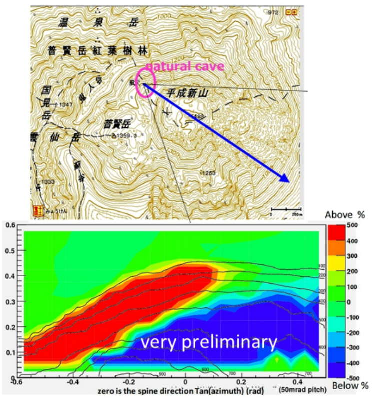

図1上：検出器設置点，方向と，溶岩ドームの位置関係.
図1下：溶岩ドームを通過するミューオン数(暫定).

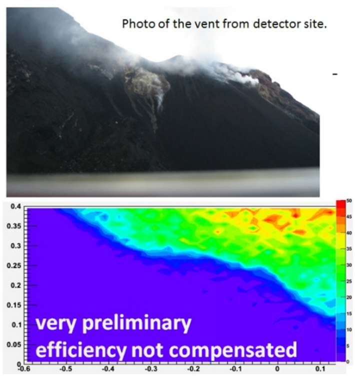

図2上：検出器設置点から見たストロンボリ火口.
図2下：ストロンボリ火道イメージング暫定結果.

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SVC48-06 Room:104 Time:May 19 12:15-12:30

Development of a multifold segmented muon detection system to improve the maximum resolvable distance of muography

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In order to perform cosmic-ray muon radiography to image a volcano with a thickness of more than 1 km, a detector with a large active area is necessary to collect the sufficient number of muon events since the penetration flux of cosmic-ray muons is reduced steeply as a function of the thickness of the target of which the muon traverses. However, the size of the active area is not a unique factor to improve the measurement. The signal-to-noise (S/N) ratio also decreases seriously as the size of the target becomes larger, and thus the density distribution cannot be accurately measured. The background (BG) noise that reduces the S/N ratio mainly consists of the fake tracks that are generated by the accidental coincidence of the vertical electromagnetic (EM) shower particles. In order to solve this problem, we developed a novel muon detection system that consists of many layers of position sensitive detectors (PSDs) in conjunction with a new analysis method to effectively reduce the BG noise. In this method, the EM shower-originated fake tracks are rejected by requesting a linear trajectory for a muon event (linear cut method) since vertical EM showers randomly hit each PSD layer and make a non-linear trajectory in the detection system. The developed detection system was tested by imaging the internal density structure (the spatial distribution of the density) of Usu volcano, Hokkaido, Japan. In this measurement, we used a muon detection system that consists of 7 layers of PSDs. One PSD layer consists of x- and y- arrays of scintillator strips to make an active area of 1.21 m^2 with a segmented area of 10x10 cm^2. The angular resolution is +/-3 degrees. The measurement duration was 1977 hours (82 days and 9 hours). This measurement yielded the following results: (A) by analyzing the region that has a thickness of more than 1000 m, we confirmed that our detection system is sensitive to a density variation of 10% in 1300-m rock; and (B) we found that there are high- and low-density anomalies beneath between Oo-Usu and Usu-Shinzan, which is consistent with the magma intrusion and the resultant fault generation suggested by Yokoyama and Seino (2000) and Ogawa et al. (1998).

Keywords: cosmic ray, muon, radiography, spatial density distribution, muography

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SVC48-07 Room:104 Time:May 19 12:30-12:45

3D imaging of the internal density structures of volcanoes by a combination of gravity and muon radiograpy

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We have developed an integrated processing of gravity anomaly and muon radiography (muography) data for determining the 3D density structures of volcanoes with high spatial resolutions (100 - 200 m). In this report, we describe the method and the case study at Showa-Shinzan Lava Dome at eastern foot of Usu volcano, Hokkaido, Japan. We focus on the resolution test using a checkerboard model to show that muography data is helpful in gravity data interpretation.

Muography is a recently developed inspection method and is based on measuring the absorption of cosmic-ray muons inside matter. From attenuation of muon flux, one can determine the amount of matter, which is given by density-length (density times length), present along muon trajectories. Forward modeling is made by supposing the region of our interest which is subdivided into several voxels with unknown density parameters. Then, both gravity anomaly and density-length data can be written as linear combinations of the unknown parameters. The observation equation is solved by using Tarantola's [1987] probabilistic approach, in which an initial guess density and a correlation length are given as a priori information.

To verify the performance of our method, we performed a resolution test using a checker-board density model superimposed on the shape of Showa-Shinzan. We compared the models reproduced from the following data sets: (a) gravity anomaly data only; (b) gravity anomaly data and muography data. The result of the case (b) is better than that of the case (a), which ensures that muography data constrains the solution well and is helpful in gravity interpretation. In the case (b), the horizontal and vertical resolutions are better than 200 m and 100 m, respectively.

Showa-Shinzan, a target volcano in our case study, was formed at eastern foot of Usu volcano in the 1943-45 Usu eruption. We applied our method to the gravity data at 30 stations on/around the dome and the muography data reported by Tanaka et al. [2007]. The results show that the western part, where the dome exists, has higher density (> 2.0 g/cc) than the eastern part of the uplifted plateau (< 2.0 g/cc). Inside the dome, we find significant density variation, characterized by two high density anomalies. One high density anomaly (2.4 - 2.8 g/cc) is located below the dome and is considered to be the lava stuck in the conduit. We conclude from this that the diameter of the conduit is about 200 m. The other dense anomaly (2.4 - 3.0 g/cc) is near the surface and is considered to be the solidified lava which was uplifted significantly at the last stage of the eruption.

Keywords: Showa-Shinzan, lava dome, gravity, muon radiography

SVC48-08 Room:104 Time:May 19 14:15-14:30

Correration between crystal size and chemical compositions; the effect of fluctuation of degree of supersaturation

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The plagioclase microlite sometimes show positive correlation between their size and chemical composition of core as shown by some studies (e.g. Noguchi et al., 2006, 2008). We analyze crystal size and An# (Ca / Ca + Na) of plagioclase microlites witch were ejected by Shinmoe-dake 2011 eruption. Crystal size is positively correlated with An#. An# of microlites range in 0.65 - 0.57, for the smallest size (10 um) and increase with size converging to 0.65 for the largest size. They are distributed within upper and lower bounds. This correlation can be explain the continuous nucleation and growth process including the evolution of melt composition, namely high and low An# evolution series.

In order to quantitatively interpret this correlation, we develop a simple model. We assume that growing surfaces of nucleated crystals are in local equilibrium with adjacent melt in their compositions, namely the effective partial coefficient is defined. We calculate An# with software package Rhyolite-MELTS (Gualda et al., 2012). We denote the rate of nucleation and crystal growth, as J [$m^{-3}s^{-1}$] and G [ms^{-1}] respectively. In the case that rate of crystallizing change P is constant, if we set J as constant, G is automatically calculated, because G depends on the total crystal surface area S and P = SG. In our calculation, G is decrease with time, because surface area is increasing. Crystals that nucleate at earlier stage grow by large G. We calculate final crystal size distribution and An# with as a varying parameter J.

The correlation between crystal size and An# become tight with increasing J, and round with decreasing J. When J is high, crystals mostly crystallize at early stage and later growth is few. When J is low, crystals grow later stage. High An# evolution series can be explain cooled at high J, and low An# evolution series can be explain cooled at low J condition. As a result of simulation, it is found that a relatively higher value of J and vice versa, corresponds to low An# evolution series in size vs. An# trends.

SVC48-09 Room:104 Time:May 19 14:30-14:45

Precursory activity and evolution of the 2011 eruption of Shinmoe-dake in Kirishima volcano-insights from ash samples

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After a precursory phreatic stage (2008 to 2010), the 2011 Shinmoe-dake eruption entered a phreatomagmatic stage on January 19, a sub-Plinian and lava accumulation stage at the end of January, a vulcanian stage in February-April, and a second phreatomagmatic stage in June-August. We examined ash samples from all the stages (Suzuki et al., in review for EPS, as of February, 2013). Component ratio, bulk composition, and particle size of the samples helped us define the eruptive stages. The juvenile particles were first found in the January 19 sample as pumice (8 vol%) and were consistently present as scoria and pumice particles thereafter (generally -50 vol%, decreasing in weaker events). The January 19 pumice has water-quench texture. After the lava accumulation, particles of that lava origin came to account for 30-70 vol% of the ash. The second phreatomagmatic stage is proposed because of fine ash and long eruption period. The SiO2 contents of bulk ash are lower in post-January 19, 2011 eruptions, reflecting lower average SiO2 contents in 2011 ejecta than in past ejecta. The free-crystal assemblages were two pyroxenes + plagioclase + Fe-Ti oxides until 2010; olivine joined the assemblage in 2011, when juvenile ash was erupted. This change is consistent with the absence or smaller sizes of olivine phenocrysts in past ejecta forming the volcanic edifice.

Aside from these scientific results, we also emphasize the importance of continuous observation of ash samples, for monitoring ongoing eruptive activity and forecasting activity change. As far as we know, ash characterization was the only method which detected the change of eruptive activity before the sub-Plinian event in the 2011 eruption; first detection of juvenile material in the January 19 sample showed that magma was rising to shallow depth. The continuous ash sample observation starting from a period of low activity (August 2008-June 2010 in the Shimoe-dake 2011 case) helps us detect appearance of juvenile material.

Keywords: Volcanic ash, Shinmoe-dake, bulk ash composition, component ratio, particle size distribution

SVC48-10 Room:104 Time:May 19 14:45-15:00

Historic records of Vulcanian eruption during 1800-1804 activity of Chokai volcano

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We briefly discuss record of historical documents about the A.D. 1800-1804 eruption of Chokai volcano, northeastern Japan. We found documents suggesting intermittent explosion, ballistic ejection of hot blocks or bombs, acoustic waves and emission of hot ash cloud, and concluded that Vulcanian eruption took place during August of 1801(July of Kyowa Gannen). Magmatic activity of 1800-1804 eruption of Chokai volcano began with Vulcanian eruption between July 2nd and July 10th and ended by emission of Shinzan lava dome around July 23rd.

Keywords: Vulcanian eruption, Chokai volcano, Historic record

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SVC48-11 Room:104 Time:May 19 15:00-15:15

Eruption scenario of Usu volcano, Japan

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The national research group on volcanic eruption forecasting is preparing the eruption scenarios (event trees with probabilities) for representative active volcanoes in Japan. At Usu volcano, the eruptive activity resumed in 1663 with the plinian and pyroclastic surge events after a sector collapse about 7 to 8 ka. Since then, five summit eruptions with the plinian columns had occurred, and three flank eruptions with phreatic to phreatomagmatic events had occurred. These eruptions were recorded in old documents or observed geophysically from the beginning of 20th Century; they occurred every 30 +/- 4 years. They ended with the formation of lava domes or cryptdomes, except for the 1663 eruption. Except for flank eruptions which are small in the scale, there is a good negative correlation between the erupted volume and frequency in log unit. The larger the erupted volume, the shorter the eruption duration. As a whole, the volume of eruption decreased with time. Seismic precursory continued generally for a few days in respective of eruption locations. The summit eruptions started, accelerating seismic activity, while the flank eruptions did after passing the peak of seismic activity. The probability of flank failure in future can be calculated about 1%, and those of the summit and flank eruptions are about 30 and 50 %, respectively. The summit eruption starts with the plinian event column in about 75% probability, while the flank eruption starts in about 70 % probability without magmatic eruption. Movement of the fault system suggesting a possibility of future failure of the volcano northern slope was observed during the last two eruptions. New eruption scenario not based only on the past eruption records may be required.

Keywords: Eruption Scenario, Event tree, Usu Volcano

SVC48-12 Room:104 Time:May 19 15:15-15:30

On the volcanic risk to the Chisong nuclear power plant in China by probable eruption of the Baitoushan volcano

Hiromitsu Taniguchi[1*], Yoshiaki Himeno[2]

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In the last presentation, I omitted the talk about the volcano risk to Chisong nuclear power plant by time restrictions. I will focus on this point and performs the talk this time.

The activity of an earthquake and the upheaval of the summit of Baitoushan volcano which started in 2002 ceased in 2005. Six years afterward, the 2011 off the Pacific coast of Tohoku Earthquake occurred and it had worries about an eruption also in Baitoushan volcano like the active volcano in Japan. For example, in North Korea, the law about an earthquake and an eruption was newly built in August, 2011. On the other hand, in China, a construction plan of the nuclear power plant (NPP) was pushed forward in Jingyu County approximately 100km away from the Baitoushan volcano. The plan was stopped by the 3.11 megathrust earthquake, but it restarted and construction is now pushed forward. Doesn't an eruption do a risk to the nuclear power plant? Supposing it does, what kind of risk is there? And what is the defense method?

This NPP uses the lake water which dammed up the source of Songhua River running down from the Baitoushan volcano as the source for cooling. Judging from a geographic characteristic, the western half of pyroclastic materials piled up on the mountaintop will change to lahar by mixing with rain or snow water, and will attack the NPP setting spot. In addition, according to the satellite image, the risk of the large-scale collapse of the western flank of mountain edifice is pointed out. This can also cause the lahar in the 100 km distant place. According to the geological map by Wei H. (personal com.), the lahar by 10th century eruption arrived at the installation predetermined area of the NPP. Even if the NPP (AP1000) of the schedule installed cannot obtain cooling water from the river, for three days, it can bear and is a nuclear reactor of new type which stops safely by air cooling after that. At this point it may be reliable to the lahar risk. Although the pyroclastic flow of 10th century could not reach to the NPP site, another probable risk may be the ash fall accompanied to the ash cloud due to the pyroclastic flow.

There are more than 15 million inhabitants in China and Russia along the river more downstream than the NPP. Therefore the examination of the thorough enforcement of the field survey and certain safety measures is necessary. Furthermore, organization establishment for the joint research among related countries of East Asia including North Korea is also desired.

Keywords: Baitoushan volcano, volcanic risk, nuclear power plant, eruption

SVC48-13 Room:104 Time:May 19 16:15-16:30

Basic Characteristics of Crustal Deformation Measurement in a Vault of the Tokachi - dakeVolcano, Hokkaido, Japan

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Tokachi-dake volcano sitting in the central Hokkaido is one of the most active volcanos in the region. In the recent 100 years, it frequently erupted including 3 major ones in 1926, 1962, and 1988. Among them the 1926 eruption triggered a lahar driven by melting snow and ice and claimed 144 lives. A lesson we can learn from the erupting history of this volcano is that each eruption was preceded by a series of small events suggesting gradually magnifying volcanic activity. In each eruption manifestations of precursory signs started to appear and then grow about several years before the eruption. Because almost 25 years, that are comparable to recent recurrence period, have passed since the last major eruption, we should be prepared for the future eruption that might come soon. It is noteworthy that there are already some signs of increased activity that probably suggest growing volcanic potential for the next eruption. Such signs are self-illumination of a spot on a wall of the 1926 crater and sporadic increase of micro seismicity around the active crater including magnitude 2.8 (JMA preliminary estimation) earthquake on February 2, 2013. The ongoing inflation localized around1962-II crater since 2006 might have to be reconsidered as one of the manifestations indicating ongoing development of volcanic potential.

The high likelihood of having precursory signals before Tokachi-dake climactic eruption encourages us to set up a network of monitoring instruments of sufficient spatial density. For the mitigating purposes it is also crucial to achieve temporally continuous monitoring with real time data transfer capability. Because of the high altitude and location in the northernmost island of Japan, the deployment of such monitoring network is difficult in reality. The biggest hindrance is originated from the heavy accumulation of snow and ice during the winter season. Instruments installed on the surface are likely to be covered by thick snow accumulation and sometimes are destroyed by avalanche or moving ice. To avoid such a risk a vault observation is preferable. For that purpose Tokachi-dake vault observatory (TKC) was constructed on the southwest flank of the volcano in 1985. Tiltmeters and extensiometer for continuous crustal deformation measurement were installed. The acquired data are being transferred to the laboratory using telemeter system working on microwave frequency.

To make the volcano monitoring reliable we should be able to distinguish signals coming from the volcanism from noises of different nature. For example precipitation is a common error source for vault measurement. For the purpose of evaluating the stability and identifying of possible error sources, we analyzed the recorded crustal deformation data (tilts and linear strain) of recent years. The data indicated that basically the measurements are quite stable. Yearly repeating variation and linear trend are found in each deformation component but those evolutions are relatively smooth and easy to identify. No variations that might be related to precipitation were recognized. On the other hand, steps were found only during winter season. A possible explanation is that crustal deformations are excited by massive motion of snow and ice, but further studies are necessary for the confidence. In the presentation, we will discuss the stability of the observation further in detail.

Keywords: Volcano, Crustal Deformation, Monitoring, Tiltmeter, Strain Gauge, Tokachi-dake Volcano

SVC48-14 Room:104 Time:May 19 16:30-16:45

Earthquake swarm activities and dilatational crustal deformation in Hakone volcano

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Hakone volcano is located in the northernmost part of the Philippine Sea plate. The Hot Springs Research Institute (HSRI) has been carrying out seismic observation in and around Hakone volcano since 1968. In June, 2001, the largest swarm activity after introduction of telemeter system occurred and it lasted about a half year. Since then, notable swarm activities were observed in 2006 and in 2008-2009. These activities were accompanied with dilatational crustal deformation.

We have been observing a new swarm activity. It started in the first days of 2013. Tilt meters operated by the HSRI have been showing crustal movements similar to that observed at the 2001 event. The GSNN data of the Geospatial Information Authority of Japan also show appearance of crustal deformation. This is the 4th time which dilatational deformation is observed by the GNSS.

We investigated progress of the dilatational crustal deformation and the swarm activity for the four cases and found a feature that crustal deformation tends to precede notable swarm activities. A notable feature is a tendency which rise occurrence of the clustered activity are delayed to the start of the dilatational crustal deformation. This suggests a possibility that occurrence of swarm activity might be forecasted by monitoring progress of crustal deformation. We discuss plausible causal relationship between a deep source of dilatation and shallower swarm activities.

Keywords: Hakone volcano, earthquake swarm, de-cluster, crustal deformation, forecasting

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(May 19-24 2013 at Makuhari, Chiba, Japan)

SVC48-15 Room:104 Time:May 19 16:45-17:00

Hybrid method to estimate discharge rate of volcanic ash by using seismic and ground deformation data

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Eruptive activity at the Showa crater resumed in June 2006 and the explosivity has increased since autumn in 2009. A method to estimate weight of volcanic ash ejected from the crater is proposed by using deflation of volcano associated with explosive eruptions and seismic amplitude (2-3 Hz) of volcanic tremor generated by non-explosive but continuous eruptions.

Keywords: Sakurajima, Volcanic ash, volcanic tremor, ground deformation

SVC48-16 Room:104 Time:May 19 17:00-17:15

Vertical ground deformation in and around Sakurajima volcano measured by precise leveling survey (until Dec. 2012)

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We conducted the precise leveling survey in and around Sakurajima volcano in November and December 2012, in order to evaluate the vertical ground deformation associated with the recent eruptive activity of this volcano. The survey data measured in Sakurajima are compared with those of the previous survey conducted in November 2011, resulting in the relative vertical displacements of the bench marks during the period from November 2011 to November-December 2012. The resultant displacements indicate the ground uplift at the northern part of Sakurajima. The relative ground height level at the northern part of Sakurajima at the time of November-December 2012 recovers and further exceeds the height level in around 1973, when the intense summit eruptions during the 1970s and the 1980s started. From the analysis based on a spherical source model, the inflation source is located at 9.6 km depth beneath the center of Aira caldera. The relative vertical displacements around the western coast of Kagoshima Bay calculated during the period from November 2009 (the previous survey) to November-December 2012 also show the ground uplift near the center of Aira caldera. These results suggest that the magma storage at the magma reservoir beneath Aira caldera is progressed in spite of the recent increase of the volume of ejected magma associated with the eruptive activity at Showa crater.

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

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SVC48-17 Room:104 Time:May 19 17:15-17:30

Temporal variation of HCl/SO_2 ratios in the volcanic plumes of Showa and Minamidake craters, Sakurajima volcano

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After the reactivation of Showa crater at Sakurajima volcano in June 2006, the volcano has been emitting volcanic gas from two craters, Minamidake and Showa craters. Due to the difficulty of volcanic gas sampling at this volcano, remote measurement is effective for monitoring volcanic gas composition. Notsu and Mori (2010) reported that HCl/SO_2ratio of the volcanic plume of Minamidake crater was 0.24-0.48 between 1999 and 2001, This presentation will report the temporal variation of HCl/SO_2 ratios of volcanic plumes of the two craters observed using remote FT-IR measurements.

The observations were carried out using a FT-IR spectrometer of Air Monitoring System (MIDAC Inc.). This FT-IR spectrometer equipped with a liquid Nitrogen cooled InSb detector has spectral resolution of 0.5 cm^{-1}. A movable mirror installed in front of the entrance window was adjusted to introduce the sunlight into the spectrometer. For the measurements, solar occultation method (Francis *et al.*, 1998) using the sun as an infrared light source was used due to the lack of infrared source on the flank of the volcano.

Since the plumes from the two craters mix as they flow, it is impossible to separately measure the HCl/SO_2 ratios for the respective craters by measuring the plume a few km away from the volcano. In order to separately measure the ratios, plume just above one of the craters was aimed using the sun going down behind the crater.

The FT-IR observations revealed that two craters have different HCl/SO_2 ratios. The HCl/SO_2 ratio of Showa crater is relatively stable raging 0.1-0.18 for the last three years. In contrast, the ratio of Minamidake crater varied between 0.13 and $>$0.3 and is usually higher than that of Showa crater except for the end of 2010. There is no noticeable correlation between the ratios and the SO_2 flux of the volcano. In two of the observations, we were able to separately measure the ratios of two vents in Minamidake crater (A and B craters) and found that they also have different ratios (the ratio of A crater is higher than the ratio of B crater). Some part of the large variation of Minamidake's ratio may be explained by changes in relative degassing strength of the two vents.

Keywords: volcanic gas, Sakurajima, remote measurement

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SVC48-18 Room:104 Time:May 19 17:30-17:45

Shear wave splitting measurements and shallow crustal structure of Mt. Fuji region

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Seismic activity in volcanic region have been reportedly changing after the Great 2011 Tohoku Earthquake. An aftershock(Mw 5.9) occurred on 15 March 2011 in Mt. Fuji region after 11 March 2011. The stress fields of the area can be affected by these events. A clear NW-SE trend of dike formations is observed in the vicinity of the volcanic edifice of Mt. Fuji and the maximum horizontal stress of the regional stress field in the area is presumed to be parallel to the strike of dike formations. The interactions of these major events and the regional stress field may affect the geologic processes in Mt. Fuji region. Seismic anisotropy can provide us with timely and spatial information about the seismic structure and stress fields. We measure shear wave splitting (SWS) by using MFAST (Savage et al., 2010) to interpret the upper crustal structure and stress fields of the region. We use data retrieved from seismic stations installed by ERI or NIED from 2009 to 2011. The measure trend of fast polarization directions (depth$<$20 km) in 2009 are almost N-S and the trend is not consistent with the regional maximum horizontal stresses (NW-SE). The trends of fast polarization directions did not change significantly after 11 March 2011. The number of events increased after March 2011 while the number of events whose SWS can be measured did not increase significantly. Previous studies indicate increase of the dilatational strain from 2006 and stress perturbations by the Great Tohoku earthquake and an aftershock (Mw 5.9). Lack of significant temporal change of fast polarization directions may indicate that the seismic anisotropy of the area is not sensitive to changes of the stress field by the events. At least, the stress perturbations by the Great Tohoku earthquake did not significantly affect the seismic anisotropy in the shallow ($<$20km) crust around Mt. Fuji region at the end of 2011. By contrast, Results of SWS from deep events ($>$20km) were unstable due to number of events and noise level. We expect that we can infer the relationships between regional or local stress field and seismic anisotropy from further analysis of SWS and comparison with focal mechanism and seismic structures.

Keywords: Mt. Fuji, Shear wave splitting, Volcano monitoring

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SVC48-19 Room:104 Time:May 20 09:00-09:15

A sketch in a shallow part of the conduit preceding a Vulcanian eruption

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The sub-Plinian and the Vulcanian eruptions at the Shinmoe-dake volcano were preceded by inflations at shallow depths near the summit. The inflation-deflation cycles were also recorded during the magma-effusive stage, with a typical period of one hour, synchronized with volcanic tremors or long-period events. Almost all Vulcanian eruptions were preceded by trapezoidal inflations, whose durations systematically lengthened as time progressed, and were followed by various time sequences of tilt motions, which became increasingly more complicated throughout the frequent Vulcanian eruptions. In spite of the complicated time sequences of the preceding inflations, we have found clear linearity with a constant gradient of 0.45 between the logarithm of the preceding durations versus elapsed time for each sub-stage.

During the magma-effusive stage, the conduit must have been filled up by magma, which was more degassed than in the sub-Plinian stage, including pores or porous structures. Therefore, it seems to be probable that certain parts of the conduit interior were occupied by poroelastic material, and that the strength of the conduit interior was heterogeneous. The preceding inflation should begin at this instant, gradually increasing in proportion with pressure buildup. When the pressure exceeded a yield value, the gas pocket area should be deformed plastically, causing a slight leakage of volcanic gas to the upper side in the conduit, and creating a volcanic glow and a slight deflation and/or a phreatomagmatic eruption. On the contrary, the lower side of the gas pocket area acted as a porous media, defusing the high-pressured gas to the deeper part in the conduit. This caused the deepening of the centroidal source depth approaching the eruption. During this time, the pressure confined in a closed strong magma frame must increase without any dynamic affect on the outside. Assuming that a Vulcanian eruption is induced by a catastrophic rupture of the closed magma frame in a conduit due to magma degassing overpressure, the clear linear relation could be interpreted that the degassing from the magma in the conduit declines exponentially with time. In conclusion, the observations can be consistently explained based on the assumption that a Vulcanian eruption is induced by a catastrophic rupture of the closed magma frame due to overpressure caused by magma degassing, and the degassing from magma declines exponentially with time. To sum up the above discussion, we propose a sketch in a shallow part of a conduit preceding a Vulcanian eruption.

Keywords: Vulcanian eruption, Tilt motion, Physical process in a conduit

SVC48-20 Room:104 Time:May 20 09:15-09:30

Tilt motion and volcanic tremor during lava-effusive stage in the 2011 Shinome-dake eruption

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Introduction

Observations such as tilt motions and tremors are important in considering magma behavior. Tilt motions observed near a crater may represent pressure change in conduit and tremors observed near a crater may be generated by volcanic fluid (gas, magma, water) in conduit. In order to reveal dynamics of eruptions, various observations such as tilt motions and volcanic earthquakes have been observed around volcanoes. In this research, we focused on tilt motions and tremors during lava-effusive stage in the 2011 Sinmoe-dake eruptions and revealed the character of them.

A series of eruptions at Shinmoe-dake

The Shinmoe-dake volcano started a magmatic eruption at 15:29 (JST) on 26 January 2011. Three sub-Plinian eruptions occurred between 26 and 27 January 2011, followed by two Vulcanian eruptions at 02:05 and at 12:48 on 28 January 2011. Midmorning on 28 January 2011, a small magma dome emerged from the center of the summit crater, progressively increasing in volume. After 1 February 2011, Vulcanian eruptions occurred frequently. Later, volcanic activity has continued during the year 2011 at least.

In this research, we focused on a lava-effusive stage (28-31 January). In this stage, deflation-inflation cycles of tilt motions with a typical period of one hour were observed at stations near by the summit of Shinmoe-dake (Maehara 2012). We also observed volcanic tremors related to deflation-inflation tilt motions. Only when the tilt motions were lower than the threshold, tremors occurred.

The frequency structure of tremors

The frequency structure of tremors differed in deflation stage from in inflation stage. In frequency domain under 2Hz, tremors are dominated by two frequencies (about 1Hz and about 1.5Hz) during deflation stage, but are dominated by a frequency (about 1.2Hz) during inflation stage. In frequency domain over 2Hz, the intensity of frequency structure in inflation stage is much smaller than in deflation stage only on 31 January.

Pressure source exciting tilt motions

We estimated the depth of pressure source exciting tilt motions by using the ratio of tilt amplitude recorded at two stations, under the assumption that pressure source generating deflation-inflation cycles was located under the center of crater and cylindrical pressure source. Then, we estimated pressure change dP which could generate tilt motions comparable to observation.

When the centroidal depth of pressure source was located at 600m above sea-level, the point sources extending 250m from 475m to 725m above sea-level could explain the observed ratio. In this case, at most a few MPa pressure change dP could generate tilt motions comparable to observation.

Keywords: lava effusion, tilt, tremor

Japan Geoscience Union Meeting 2013
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SVC48-21 Room:104 Time:May 20 09:30-09:45

Spatio-temporal variations of the volcanic tremors on Kirishima volcano estimated by dense seismic array

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Shinmoedake Volcano, mount Kirishima, Japan, began a series of eruptions on January 19, 2011. We installed 25 seismometers near Shinyu springs located at about 3 km away from the crater. On the other hand 16 seismometers were installed at Hinamori-dai located at about 5 km away from the crater by Nagoya University.

Detection of spatial and temporal variations of volcanic tremors is important for understanding the mechanism of volcanic eruptions. However, short-term temporal variations within a tremor event have not been revealed. Here, we observed change in the seismic ray direction during the volcanic tremor sequence through MUSIC spectrum processing and estimated spatial distribution of the source of volcanic tremors by combination of the two dense seismic arrays. MUSIC spectrum processing was applied to seismograms of a volcanic tremor occurred on February 2, 2011, and its duration was about 40 minutes. Most part of the tremor arrived from Shinmoedake crater. However, at some parts of the tremor sequence the slowness vectors show change in the tremor's source location. One part of the tremor with large slowness and with relatively long duration was generated at a shallow region beneath the crater. Another part of the tremor with short duration was found near Ohnami pond, 3.3 km northeast of the crater. Because of using a constant velocity structure model, accuracy of locations for tremor with small slowness was not enough to discussion relationship between their and volcanic activities. We will estimate distribution of the volcanic tremor source by using more realistic velocity model, and compare other geophysical data in order to understand the eruption activity.

Keywords: Shinmoedake, volcanic tremor

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SVC48-22 Room:104 Time:May 20 09:45-10:00

Hypocenter determination of B-type earthquakes at Miyakejima volcano using the envelope correlation method

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After the 2000 eruptions, Miyakejima volcano still continues to emit large amount of volcanic gases. Meanwhile, B-type earthquakes have also been continuously and frequently observed after the eruptions, and often show emergent onsets of P- and S-phases, which makes the application of conventional phase-picking hypocenter determination rather difficult. Recently, Uchida et al. (2012) analyzed B-type events at Miyakejima volcano, which are observed by Japan Meteorological Agency from August 2010 to April 2011, and succeeded in determining 18 % of the observed 1,049 B-type events by stacking the waveforms of earthquake families to read the P- and S-wave onset times. However, the hypocenters of the rest of B-type events still remain unknown.

In this study, aiming to locate all of the B-type earthquakes at Miyakejima, we apply the method of Obara (2002), which was used for non-volcanic deep tremors on the subducting Philippine Sea Plate in south west Japan, to the seismograms observed at nine stations located within 4 km of the summit. At each station, we compute a RMS envelope from 4 - 8 Hz band-pass-filtered three-component seismograms, and measure the differential travel times between stations by taking cross-correlations of the envelopes. We assume that the envelope is composed of S-wave traveling with the velocity of 1250 m/s, as in Uchida et al. (2012).

To assess the applicability of the method to B-type earthquakes, we determine the hypocenters of individual events in each of the four earthquake families by applying the envelope correlation method, and compare the resultant hypocenters with those obtained from phase picking of the stacked waveforms. As a result, we found that the epicenters located by the envelope correlation almost coincide with those determined by the phase picking. On the other hand, the method sometimes yields large error in depth. That is probably due to the difficulties in measuring the S-wave travel times from the envelopes. To improve the accuracy, we need to consider the envelope broadening by scattered waves, surface waves and/or reflection phases.

We then apply the envelope correlation method to all of the observed 1,049 B-type earthquakes, of which about 80 % had never been located, and successfully locate them in an automated way. As a result, we found that 97 % of them are located within a 1.5 km diameter centered on the southern part of the summit caldera, where continuous fumarolic gas emission occurs. It strongly suggests that the occurrence of B-type earthquakes is related to the gas emission activity at Miyakejima. Those hypocenters are distributed at the depths shallower than 3 km. Our study shows the usefulness of the method as a tool to monitor volcanic earthquakes which are difficult to locate by conventional phase picking.

Keywords: Miyakejima volcano, B-type earthquake, hypocenter determination, envelope correlation method

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SVC48-23 Room:104 Time:May 20 10:00-10:15

Wave properties of explosion earthquake and precursory tilt change associated with vulcanian eruptions at Lokon volcano

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Lokon-Empung is one of the most active volcanoes in Indonesia. It is a twin volcano located in the north arm of Sulawesi Island. The volcano began eruptive activity at Tompaluan crater, which is on the ridge connecting Lokon and Empung peaks, in the year of 1829 after several hundred years of quiescence. Vulcanian eruption activity is considerably high, so we began temporal seismic and tilt observation at Lokon-Empung volcano since September 2012 to understand the mechanism of the vulcanian explosion and its preparatory process. Here we report wave properties of explosion earthquakes and precursory tilt changes as a preliminary step toward the source mechanism analysis.

Four broadband seismometers (Trillium 40) are deployed around the Lokon-Empung volcano in the distance range of 1.6 - 6.8 km from the Tompaluan crater. A high-sensitive tilt meter (Pinnacle Denali) is also installed at the closest station WAILAN which is connected by a wireless network to Kakaskasen Volcano Observatory (KKVO) in Tomohon City. Each seismometer is connected to a data logger (HKS-9550) to record seismic data in a CF card with an A/D resolution of 24 bit and a sampling rate of 100 Hz with time stamps of GPS clock. Tilt data digitized every one second within the tilt meter are transmitted to a laptop PC at KKVO once per day. Seismic data of WAILAN is sent to Japan as win format packet through the wireless network and global internet on a trial basis.

An explosion earthquake on September 28 was relatively small, but recorded at all four seismic stations. Polarity of P waves show compression at all stations. Seismogram of the station TINOOR, about 2.6 km northeast of the crater, has the largest amplitude among four stations and shows monochromatic waveform different from those of the other stations. Since a tectonic earthquake shows similar waveform and a noise spectrum has a dominant peak around 2 - 4 Hz corresponding to the monochromatic waveform, it is recognized as the special site effect at TINOOR. Explosions on October 5 and November 11 had obvious onset and short duration within about 1 minute. Among the analyzed events, the explosion earthquake on October 5 has the largest amplitude in the order of 0.001 m/s at the station WAILAN. The visual report on the height of ash column is about 1500 m above the crater. Before the October 5 eruption, small inflation phase around crater area can be seen in tilt record. The amount of tilt change is about 80 nanoradian. Duration of the inflation phase is about 40 minutes, which is almost same order to those found in Semeru volcano (3~30 minutes). Polarities of P wave of October 5 and November 11 explosions are both compression as with the explosion on September 28. Although the seismograms of these three explosions seem different each other in original non-filtered traces, we can find very similar waveforms in the lower frequency band below around 1 Hz. This similarity indicates that the explosion mechanisms of these events have common physical process. In the low-pass filtered seismogram, large dilatational phase is identified after the compressional P wave and then clear retrograde motion representing Rayleigh wave appears. These waveform characteristics are similar to the explosion earthquakes at Sakurajima, Suwanosejima that often explode with Vulcanian eruptions. While, small deflation phases appearing about a few seconds before the initial compression phase that are reported for the explosion of Suwanosejima and Semeru volcanoes are not well recognized.

Keywords: Vulcanian eruption, explosion earthquake, tilt change

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SVC48-24 Room:104 Time:May 20 10:15-10:30

Source amplitudes of volcano-seismic signals determined by the amplitude source location method

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The amplitude source location (ASL) method, which uses high-frequency amplitudes under the assumption of isotropic S-wave radiation, has been shown to be useful for locating the sources of various types of volcano-seismic signals. We tested the ASL method by using synthetic seismograms and examined the source amplitudes determined by this method for various types of volcano-seismic signals observed at different volcanoes. Our synthetic tests indicated that, although ASL results are not strongly influenced by velocity structure and noise, they do depend on site amplification factors at individual stations. We first applied the ASL method to volcano-tectonic (VT) earthquakes at Taal volcano, Philippines, where the seismic network consists of eight seismometers (five broadband and three short-period seismometers). Our ASL results for the largest VT earthquake showed that a frequency range of 7-12 Hz and a Q value of 50 were appropriate for the source location determination. We proposed a two-step approach to minimize site effects on the source amplitude estimation as follows: The source location is first determined by using a frequency band of 7-12 Hz and Q = 50 with site amplification corrections, and then the source amplitude is estimated by using waveform data at broadband seismic stations only without site amplification corrections and a reference frequency band of 5-10 Hz and Q = 50. Using this two-step approach, we systematically applied the ASL method to VT earthquakes at Taal, and estimated their source locations and amplitudes as well as seismic magnitudes. We similarly analyzed LP events at Cotopaxi and explosion events at Tungurahua. At all three volcanoes, we found a proportional relation between the magnitude and the logarithm of the source amplitude without any strong dependence on event type. At these three volcanoes, all of broadband seismometers had been installed in a similar way, which may have minimized site effects. The ASL method can be used to determine source locations of small events for which onset measurements are difficult, and thus can estimate the sizes of events over a wider range of sizes compared with conventional hypocenter determination approaches. Previously, there has been no parameter widely used to quantify the sources of volcano-seismic signals. This study showed that the source amplitude determined by the ASL method may be such a useful quantitative measure of volcano-seismic event size.