Development of mobile sensor for volcanic observation “HOMURA”: Test campaigns for a long-term operation

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Monitoring of phenomena near craters of active volcanoes is important to learn symptoms of volcanic eruptions and to understand eruption dynamics. At present, some devices such as crater camera, volcanic gas sensors, and seismographs have been installed in calm periods of volcanic activity. On the other hand, there are some cases where we cannot install new monitoring devices at volcanoes without enough devices after volcanic eruptions occur. In this case, unmanned robots are useful. We are trying to develop a practical unmanned-ground-vehicle-type robot for volcanic observation that carries out monitoring near active craters. We named this system "Homura". In this presentation, we report results of test campaigns for operation of Homura in outdoor fields.
At present, we have developed a prototype of Homura. It is a small-sized, vehicle-type robot with six wheels (750 x 430 x 310 mm in dimensions and a weight of about 12 kg). It is remotely controlled with mobile phone radio waves; it can move in volcanic fields and send real time data of sensors (camera, thermometer, and CO_2 gas sensor for test) equipped in the vehicle to the base station. Power consumption of Homura is about 20 W in an operation state and less than 0.1 W in an idle state, so that we can use Homura for a long time by intermittent operation.
We carried out a test of Homura for about one month at Kyoto University in January, 2015. Homura was put on the roof of a building and operated by remote control. Although Homura was exposed to snow and rain during the test, all the functions of Homura (the traveling system and sensors) normally worked.
From Feb. 19th to Apr. 8th, 2015, we carried out a test campaign of Homura at Iwo-yama to examine if Homura can work for a few month in natural volcanic fields. Iwo-yama is one of craters in the Kirishima volcanic field, SW Japan; the area within 1 km from the crater was an off-limit area from Oct. 24th, 2014 to May 5th, 2015 because volcanic seismicity there was active and eruption might occur. On Feb. 19th, we carried and put Homura at the rim of the crater. Unfortunately, mobile phone connectivity was not entirely stable around Iwo-yama. Then, we decided not to move Homura and only to obtain real time data of the sensors. After we returned to our office, we operated Homura for one to two hours every day until Apr. 8th. Although the weather was often bad (rain, fog, or cold temperature) during the test campaign, we could completely operate Homura without any trouble. On Apr. 8th, the battery in Homura ran down. After we collected Homura from Iwo-yama and recharged the battery, Homura perfectly worked again. The results of this campaign indicate that Homura stably functions for a long time in volcanic field. Homura is useful as simple monitoring station in volcanic fields where mobile phone connection is available.
This work was supported partly by a grant-in-aid for scientific research from the Japan Society for the Promotion of Science and the Earthquake Research Institute cooperative research program.

Keywords: robot for volcanic observation, remote control, realtime data

Continuous observation of visible plume quantity, gas chemistry and water quality in Owakudani, Hakone volcano (2015-2016)

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We monitored quantity of visible volcanic plume from Owakudani fumarolic area, Hakone volcano before and after the phreatic eruption in 2015. Quantity of volcanic plume is represented by number of white pixel in pictures taken by a time-lapse camera installed near the eruption vents. The amount of volcanic plume increased soon after the eruption in June 29 to July 1 and decreased gradually until early November; however it increased again and marked its peak in December.
We also monitored water quality of downstream of the vent and volcanic gas around Owakudani area. Our monitoring shows that water temperature, its Cl content and CO2 content of volcanic gas also increased in December.
Such relationship between plume quantity and water and gas chemistry could indicate that there are aseismic upwelling of geothermal water in December.

Estimation of ground movement around the 62-2 Crater of Tokachi-dake Volcano from the Geomorphic Image Analysis of Differential LiDAR DEM

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In this study we estimated ground movements in around the 62-2 Crater of Tokachi-dake Volcano where ground movement was suggested by InSAR and GNSS observations of some research institutes, using the Geomorphic Image Analysis of differential LiDAR DEM from 2009 through 2015. And we tried to estimate the hazardous area of slope failure and debris flow area, concerned with ground movement or volcanic activity.
The topographical data used in this research is two times of 2mDEM by the airborne laser survey in 2006 and 2015. And the gray-scale gradient slope angle map was provided for Geomorphic Image and the existing software for PIV analysis was used for image matching analysis, and the results were combined with vertical component calculated from multi-temporal DEM.
The range of the ground movement for six years estimated by the Geomorphic Image Analysis is almost conform to the result by InSAR of most recent one year and the results of the nearest GNSS observations for these past several years.
These results indicate the ground deformation by volcanic activity around the 62-2 Crater of Tokachi-dake Volcano continues recent years. However, large displacement in a wide area was not observed in this study. And it may be said that the sign of the large-scale slope failure around Mae-Tokachi, suggested by the accumulation of the displacement by GNSS observations, couldn't be confirmed in this stage.

Keywords: Volcano, Airborne LiDAR, Differential LiDAR DEM analysis, Image matching analysis

Feasibility study of volcano monitoring using microsatellite: a case of Hodoyoshi-1

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We conducted a feasibility study of volcano monitoring using microsatellite. In order to monitor volcanic activity, it is necessary to observe the volcano region frequently by using spaceborne, airborne and ground based observation equipments. A constellation of microsatellites with an optical sensor is very useful to conduct volcano observation. Hodoyoshi-1 is a 60 kg, cubic microsatellite 60 cm on each side with aimed at Earth observation. Hodoyoshi-1 can obtain images with a ground resolution of 6.7 m in multiple spectral bands with a swath width of 28 km. Comparing a Hodoyoshi-1 color image with a red relief image map of volcano region, we can interpret lava flow, pyroclastic flow, landslide and so on. And, we can monitor coverage of thermal area and influence on forest using near infrared image and NDVI image.

Acknowledgment
We would like to thank the Axelspace Corporation for providing of Hodoyoshi-1 data.

Keywords: microsatellite, volcanic activity, monitoring

Study of volcanic ash research using synthetic aperture radar satellite

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In the example of Sakurajima and Unzen eruption, etc., after a lot of volcanic ash was deposited around the volcano, has been known that the debris flow occurs frequently in a little rain. Therefore, knowing the volcanic ash area and thickness deposited is very important in order to execute the measures of debris flow.However, in addition to expanding the evacuation area upgrade the volcanic alert level by the eruption, in order to prevent the aircraft trouble, it is difficult to survey the deposition conditions of volcanic ash from the ground and aircraft.Therefore, in order to know whether it is possible to the deposition area and the deposition thickness of the survey of the volcanic ash, we were surveyed using a satellite that can be observed in a safe and scheduled.Survey is a Mount Aso, the survey period was from November 28, 2014 to December 3, 2015. In this period, from 25 November 2014 to May 21, 2015, and September 14 to October 23, 2015, continuous eruption has occurred.As a result of analyzing the color composite image, it was possible to confirm the ash deposition area and volcanic bombs arrival areas. If the volcanic ash deposit thickness is more than several cm, the result that it is possible to judgment by the NDSI was suggested. However, since the survey site is very limited, there is a need for data accumulation and data analysis.

Keywords: synthetic aperture radar satellite, volcanic ash research, mount ASO

An estimation method for the amount of fall-out ashes using the photo images

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When the volcano erupted, to estimate the eruptive mass of magma is important in revealing the scale of the eruption. However, in order to estimate the amount of fall-out ashes, it requires many field works. In these days, it is possible to know the appearance of fall-out ashes to immediate through the Internet media such as SNS. In this study, we conducted filed survey at the time of actual fall-out ashes from Sakurajima and Aso volcanoes. Also it was carried out fall-out ashes from Sakurajima volcano measurement by experiment. And we tried estimation method for the amount of the fall-out ashes using the photo images. From the images obtained by the fall-out ashes measurement by experiment, it can be said that it is possible to grasp weight per unit area of approximately.

Keywords: amount of fall-out ashs, photo images

Development of a method for estimating the weight of volcanic ash deposits using image analysis

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There are many volcanoes in Japan and several of them erupt each year. Mostly, these eruptions are small and it is difficult to arrive at the area in time to collect samples because most of the eruptions are unpredictable. When the volcanoes erupt explosively, pyroclasts are emitted into the air, and the small particles are especially damaging to the lives of the people. To reduce this damage, it is necessary to obtain data related to volcanic ash (i.e. the thickness of volcanic ash deposits and grain-size distribution), and produce an action plan quickly. Currently, we collect samples by distributing sampling boxes manually on the ground when the volcanoes erupt. This method requires a lot of time and human resources. Therefore, we aim to develop a method of collecting ash deposit data by taking photos and analyzing them. At first, we started field work in Sakurajima volcano in order to develop a more efficient system. With this field work, we considered what the proper material and color of ash-receiving sheets should be, and how to control the amount of light. As a result, the problems inherent was revealed in taking photos of volcanic ash. Then, through laboratory experiments with artificial ash-fall deposits on the sheets, we obtained results showing a certain relationship between the grain-size of volcanic ashes and the weight per unit area regardless of the volcano of origin.

Keywords: Image Analysis, Volcanic Ash

Distribution, volume and emplacement mechanism of Aso-4 large-scale pyroclastic flow

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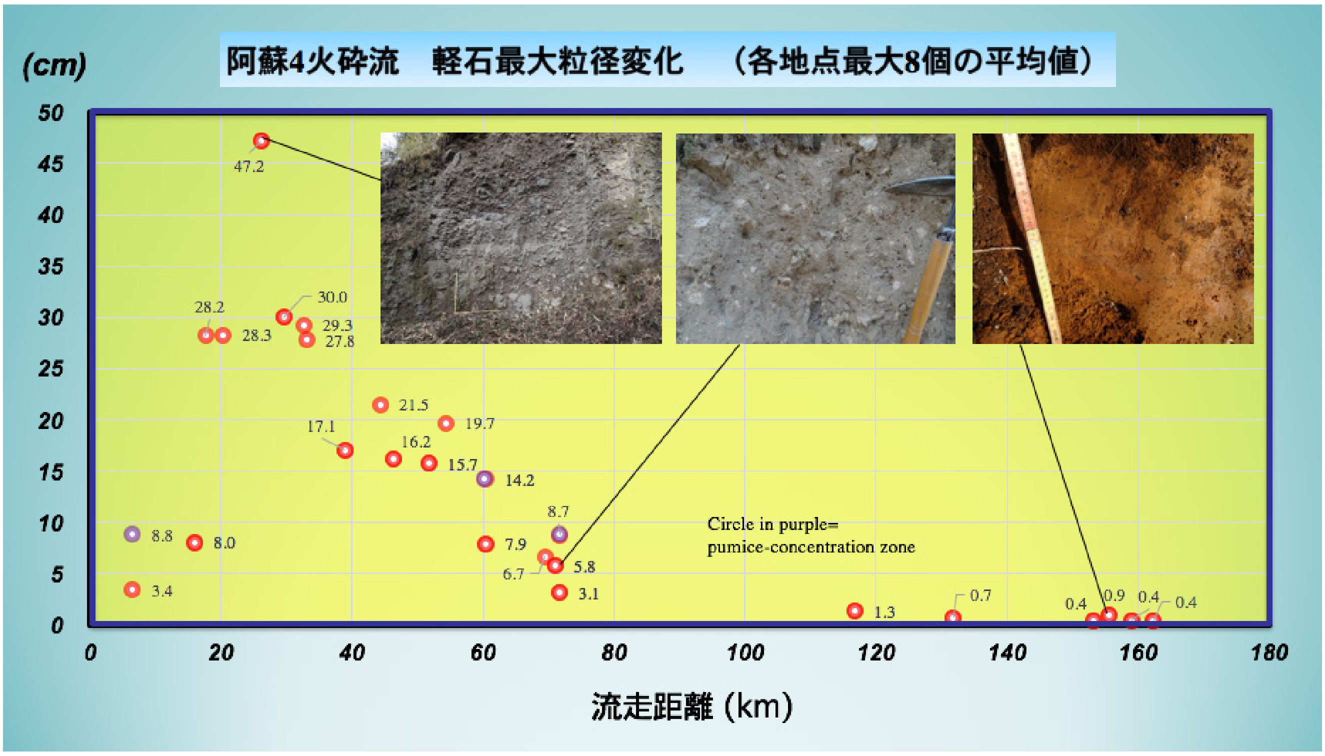
Distribution, volume and emplacement mechanism of the 90 ka large-scale Aso-4 pyroclastic flow are surveyed and discussed. The large-scale pyroclastic flow (ignimbrite) usually cause catastrophic disasters around the caldera as shown at 1883 Krakatau pyroclastic flow, which caused 36,400 fatalities. The 90 ka large-scale Aso-4 pyroclastic flow reached as far as more than 160 km from the source. The precise distribution, volume and emplacement mechanism studies of large-scale pyroclastic flows are necessarily to mitigate the volcanic disasters.

The estimated current total distribution area is about 2,500 km^2. The estimated total volume of Aso-4 pyroclastic flow in DRE are about 20-60 km^3 (current), and 50-140 km^3 (just after the event). The maximum size of pumices and lithics of 8 samples in each outcrop in the main pyroclastic flow deposits (except the lag breccia facies) were measured in E and NNE directions from the source. The size of maximum pumices at up to 16 km outcrops show 3-9 cm, 17-20 km show 28 cm, 26 km near the break-in-slope point shows 47 cm. Then the maximum sizes gradually decrease up to 3 cm at 72 km. The maximum sizes of pumices at outcrops in Yamaguchi prefecture (132-162 km from the source) show 0.4-0.9 cm. The maximum sizes of lithics at 6.5 km from the source show 1-2.5 cm, 16 km show 11.2 cm and gradually decreases up to 0.3 cm at 117 km in Kita-Kyushu. No measurable lithics are contained in outcrops in Yamaguchi prefecture. Further investigations are planning including unit correations and grain-size variations in other directions.

The relatively small maximum size of pumices and lithics near the source suggest that the quite high turbulence of pyroclastic flow was enough to transport large pumices and lithics due to turbulence within or near the volcanic plume. The maximum size of pumices reached 47 cm at the break-in-slope region on the original slope (26 km from the source) suggests sudden drop of large pumices at this point due to hydraulic jump. The gradual decrease of maximum size of pumices and lithics up to 72 km suggests deposition from the bottom of turbulent pyroclastic flows. Subtle revere grading of pumices about 20-70 cm in thickness are sometimes observed within the deposit. This feature indicates that interaction of pumices at the final stage of deposition, suggesting relatively high-density density currents were formed at the bottom of pyroclastic flow and successively settled forming depositional subunits. The thickness of pyroclastic flow deposits in Yamaguchi prefecture are about 10 cm –6 m in thickness and sometimes show surge features at relatively high area. The sizes of maximum pumices are less than 1 cm and no measurable lithics are contained. These features suggest that the pyroclastic flow reached to Yamaguchi prefecture was relatively low-density current with only small-size materials.

Keywords: Aso, pyroclastic flow, large-scale, emplacement mechanism, distribution, volume


阿蘇4火砕流　軽石最大粒径変化　（各地点最大8個の平均値）
(cm)
50
45
40
35
30
25
20
15
10
5
0
47.2
28.2
28.3
30.0
29.3
27.8
21.5
19.7
17.1
16.2
15.7
14.2
8.8
8.0
8.7
7.9
6.7
5.8
3.4
3.1
1.3
0.7
0.4
0.9
0.4
0.4
Circle in purple=
pumice-concentration zone
0
20
40
60
80
100
120
140
160
180
流走距離 (km)

Volcanic Disaster Mitigation Measures of the Asia-Pacific Region Earthquake and Volcanic Hazards Information Mapping Project

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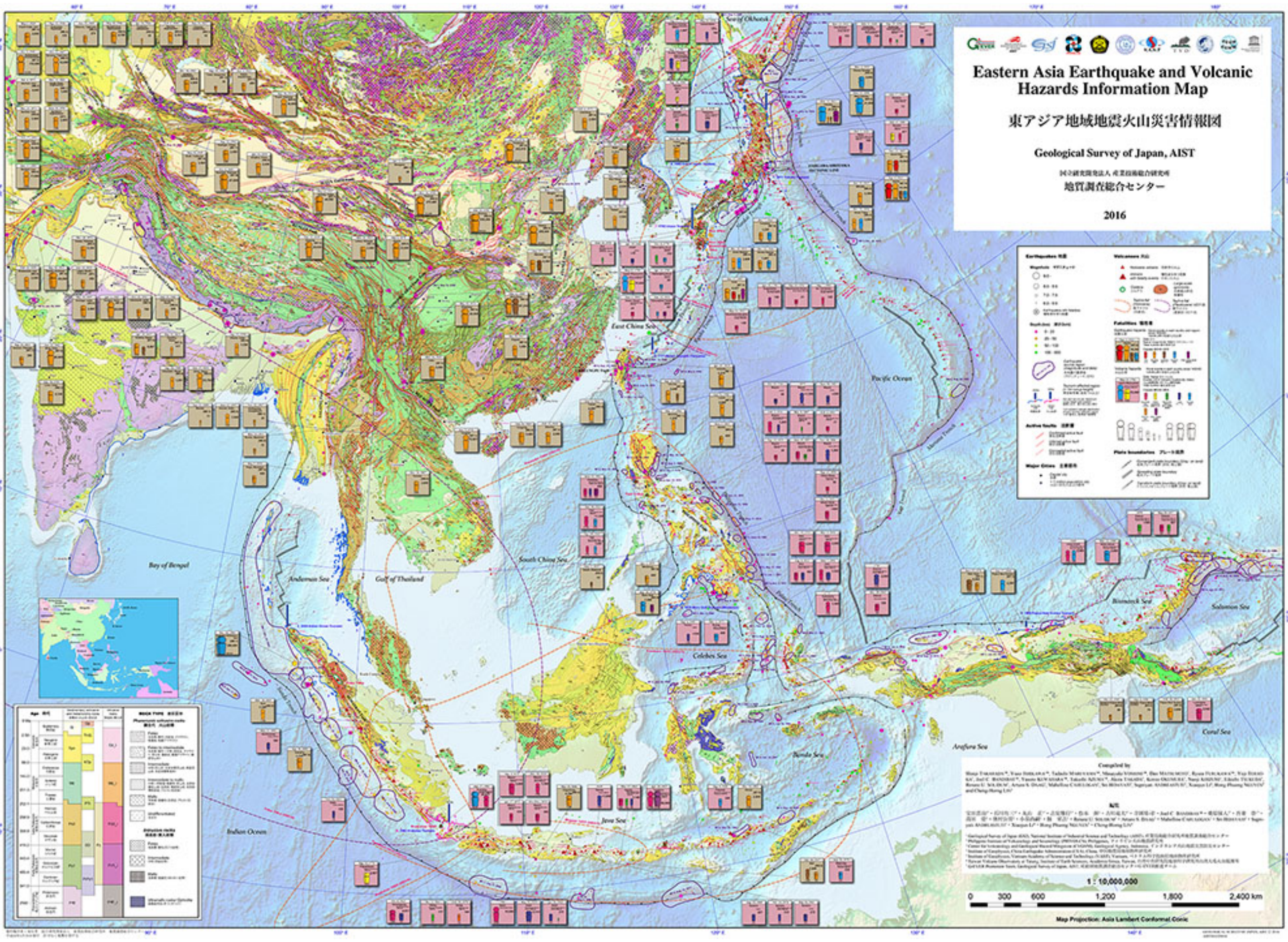
The G-EVER Consortium promotes earthquake and volcanic hazards reduction activities through the collaboration of different research institutes worldwide. The G-EVER Promotion Team in Geological Survey of Japan has been worked on publishing a new “Eastern Asia Earthquake and Volcanic Hazards Information Map” as a part of Asia-Pacific region earthquake and volcanic hazards information mapping project since 2012. The Eastern Asia Earthquake and Volcanic Hazards Information Map shows distribution of volcanoes, calderas, pyroclastic falls and ignimbrites, fatalities of major volcanic events, active faults, earthquakes hypocenters and source areas, fatalities of major earthquakes, tsunami hazards, geology, and tectonics.
Distribution of Holocene volcanoes (<10ka) is shown on this hazard information map. East and Southeast Asia experienced 3,446 eruptions during Holocene time. Sorting by VEI allows us to list up 4 eruptions of VEI7, 19 eruptions of VEI6 and the rest of them are VEI5 or lesser. Extent of pyroclastic fall deposit is shown mostly based on literature describing the area of pyroclastic fall deposits that currently exist. On this map we adopted 4 eruptions of VEI7 (Tambora 1815AD, Rinjani 1257AD, Chambaishan 938AD, Kikai 7.3ka) and 7 eruptions of VEI6 (Pinatubo 1991AD, Krakatau 1883AD, Rabaul 6C, Witori 3.4ka, Mashu 7.6ka, Ulreung 10.7ka, and Moekeshi 9.5ka). We added 3 Pleistocene large-scale eruptions (Aira 30ka, Toba 74ka, and Aso 90ka), which are well-documented and can be used for comparative examples for hazard assessment. Distributions of calderas and large-scale ignimbrites (VEI6-8) are shown on the hazard information map. Twelve large-scale ignimbrites are selected on the map. We adapted one ignimbrite of VEI8: Toba, seven ignimbrite of VEI 7: Aso 4, Ito, Shikotsu, Toya, Kussharo 4, Changbaishan, and Tambora, four ignimbrite of VEI 6: Hachinohe, Krakatau, Pinatubo, and Rabaul.
Fatalities of major volcanic events are compiled to facilitate visual understanding of volcanic disasters in Eastern Asia. The number of fatalities and the main causes of deaths due to volcanic events are displayed. Five to thirty worst top volcanic events are chosen in each country: Japan (24), Philippines (15), Indonesia (30) and Papua New Guinea (5). The number of fatalities is categorized by seven causes; pyroclastic flow, debris avalanche, tephra fall and ballistic, lahar, tsunami, volcanic gas and other related death. The worst top 24 fatalities caused by volcanic events in Japan after 1400AD are listed. The most hazardous volcanic event in Japan was the 1792 Unzen Mayuyama debris avalanche, which caused 15,000 fatalities. The 2nd hazardous volcanic event was the 1783 Asama eruption, which caused 1,491 fatalities due to pyroclastic flow, debris avalanche, and lahar. The 3rd event was the Oshima-Oshima 1741 debris avalanche, which caused 1,467 fatalities at the coastal area due to tsunami. The worst top 30 fatalities caused by volcanic events in Indonesia after 1400AD are listed. The worst event is the Tambora 1815 caldera-forming eruption (VEI7) which caused 60,000 fatalities. About 11,000 people were killed by pyroclastic flows and about 49,000 people died due to famine and disease. The 2nd worst event is the Krakatau 1883 caldera-forming eruption (VEI6), which caused 36,417 fatalities. About 2,000 people were killed by pyroclastic flows and 34,417 people were killed by the associated tsunami. The 3rd worst event is the Kelut 1586 eruption, which caused about 10,000 fatalities due to pyroclastic flows.
The contents of Eastern Asia Earthquake and Volcanic Hazards Information Map are planning to be

implemented on the online hazard information system (http://ccop-geoinfo.org/G-EVER). We believe that this hazards information map will provide useful information for earthquake, tsunami, and volcanic disaster mitigation efforts.

Keywords: Eastern Asia, Volcano, Earthquake, Disasters, Hazards



Slush avalanche of Mount Fuji on February 14, 2016

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On February 14, 2016, slush avalanches were occurred at Fuji volcano. We took an aerial photo and performed the comparison with climatic conditions and seismometer data. This is a preliminary report about a slush avalanche of Mount Fuji on February 14, 2016.

Keywords: slush avalanche, aerial photo, Fuji volcano


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Volcanic Disaster Mitigation Plan of Sudden Eruption for Tourists and Climbers of Mount Fuji

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After Mt. Ontake eruption on 27 Sept. 2014, it is required to prepare an evacuation plan for climber and tourists from a sudden eruption of Mt. Fuji which is the largest active volcano in Japan. There are about three million people climbing up Mt. Fuji during summer season. When the eruption starts they have to evacuate as soon as possible, and so we need to show the safety evacuation routes for them. Yamanashi prefecture produced and published the evacuation route map for climbers and tourists of Fujiyoshida-route of Mt. Fuji. We discuss problems and the usage of this map.

Keywords: Mt. Fuji, Volcanic Disaster Mitigation, evacuation

Temporal-spatial heterogeneity of volcanic eruption records in Japan

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Under-recording of events must be taken into account in estimating recurrence rates of explosive eruptions using volcanic eruption record. In the Large Magnitude Explosive Volcanic Eruptions (LaMEVE) database (Crosweller et al., 2012, Brown et al., 2014), Japanese events account for about 39 % of the entire set of eruptive events (Kiyosugi et al., 2015). An analysis[k1] of the Japanese eruption events show an inverse correlation between VEI and degree of under-reporting suggesting that even larger VEI eruptions are under-recorded in the Quaternary. For example, 89 % of VEI 4 events, 65–66 % of VEI 5 events, 46–49 % of VEI 6 events and 36–39 % of VEI 7 events are missing from the record at 100 ka, 200 ka, 300 ka, and 500 ka, respectively (Kiyosugi et al., 2015). Comparison of frequencies of Japanese and global eruptions suggests that under-recording of the global database is 7.9–8.7 times larger than in the Japanese dataset (Kiyosugi et al., 2015).

In addition to the analysis of the entire Japanese eruption events, temporal-spatial heterogeneity of the dataset must be considered in modeling the under-recording of events. The main mechanisms of under-recording are absence of historical records, erosion and alteration of tephra deposits, burial of tephra deposits by younger deposits and disappearance of the source volcano itself due to burial or erosion. Therefore, under-recording of events varies temporally and spatially, reflecting geological and historical backgrounds. For example, an analysis of the Japanese eruption events suggest that many large eruptions are missing in the Izu-Bonin arc because the volcanic arc consists of small volcanic islands where wide-spread tephra deposits are less likely preserved. Understandings of the under-recording in different geological settings improve the estimation of recurrence rate of volcanic eruptions. Furthermore, Koyama (1999) pointed out that the historical record of Japanese volcanic eruptions increases in two time periods (from the end of the 7th century to A.D. 887 and from the beginning of the 17th century to the present) due to political and social background in Japan at those times. Because frequency of the recent eruption events, which includes the historical records, is an important factor to model under-recording of events, detailed study of the temporal heterogeneity is required.

I will show results of analyses of the temporal-spatial heterogeneity of Japanese eruption events. Because the Japanese events account for about 39 % of the entire set of eruptive events, analysis of the Japanese data contributes to understanding the under-recording of events and estimating recurrence rate of the global dataset.

Reference:

Brown et al (2014) Journal of Applied Volcanology, 3:5.
Crosweller et al (2012) Journal of Applied Volcanology, 1:4.
Kiyosugi et al (2015) Journal of Applied Volcanology, 4:17.
Koyama (1999) Journal of Geography, 108(4), 346-369 (in Japanese).

Keywords: eruption database, under-recording of volcanic events, temporal-spatial heterogeneity

The volcanic structure around Akita-Komagatake by the boring core and wide area specific resistance

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The specific resistance distribution of the wide area was acquired by airborne electromagnetic survey to Akita Komagatake of quaternary era located in Akita and Iwate border between prefectures and the surrounding volcanic structure as well as boring exploration of depth 100m was conducted in Akita Komagatake hillside, so the result is introduced.
Boring exploration was conducted in an altitude 920m spot along a prefectural highway AkitaKomagatake line on Akita side. This spot is the area where Iwaisawa lava flow is distributed over a surface in Fujinawa and others (2006). Even 10.22 m of depth is regarded as the unit of this Iwaisawa lava flow as a result of the core confirmation, and the unit regarded as the upper part Tazawa-ko Lake high plain lava picks up the layer which seems to be scoria fall and a surge lodgment thin, and ranges to from depth 10.53m to 28.18m. Thick different (more than 40 m) lava ranges to from depth 58.9m to the deepest 100m. It was found that a detritus avalanche lodgment exists between the lava with this thick depth and the upper part Tazawako high plain lava. A detritus avalanche lodgment is divided into the matrix independent parts, the mass of rock independent parts, the jigsaw crack developmental parts and the mass of rock matrix intermingled parts, etc., and a change in organization can observe well from a core. Though this detritus avalanche lodgment makes Mt. flow interspersed among AkitaKomagatake foot of a mountain in a Sendatsu riverside, there is a possibility same as the Sendatsugawa detritus avalanche lodgment distributed (Doi and others, 1997). When a detritus avalanche lodgment shows the resistance value compared with roughly 150-170 ohm of inside-appearance low little and picks only the specific resistance band out when it's compared with resistivity distribution compared with the three dimensions by after-mentioned airborne electromagnetic survey, it's fan-shaped little to the foot of a mountain from the Katakuradake direction, because the aspect which spreads is seen, causality with northern caldera formation before Katakuradake formation is suggested.
On the other hand, airborne electromagnetic survey, AkitaKomagatake, the investigation including the Quaternary volcano body old little which are Sasamoriyama who ranges and Yunomoriyama, etc. in the northeast direction as well as build were performed and the specific resistance distribution of the wide area was acquired. It becomes as follows as the overall tendency of the specific resistance distribution.
AkitaKomagatake, the part with the low ratio resistance value is local by a body, and it's limited mainly around the northern white deterioration area in the 2nd horse's hoof type crater trace, Katakuradake crater remaining unknown trace and bottom of the valley in Mizusawa.
A high specific resistance area and a low specific resistance area are distributed over an old volcanic structure on the northeast side like a patchwork.
It's a low specific resistance area even around the mountain top in particular at Yunomoriyama, and it's supposed that groundwater is expensive and that deterioration is progressing by heat water.
I'm also becoming a low specific resistance in particular at the topography part circumference where the trace fluidized with landslide is seen (Yunomori Yama north side and the nipple hot spring village south side), and hydrothermal activity is caused in the past, and makes them suppose to have made fluidization in landslide and earth and sand occur.
I can think it's to check the specific resistance distribution, and it's possible to grasp the

structure of the whole volcanic structure and the reach with a possibility that catastrorphic sediment transport of sector collapse and landslide, and I'd like to go as the reference data for taking volcanic erosion control measures from now on.

Keywords: Akita Komagatake, Airborne electromagnetic survey, Boring exploration, Sector collapse, Detritus avalanch, Volcanic structure

Reconsideration about the distribution of Narugo-Nizaka tephra (Nr-N)

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Narugo volcano is a Quaternary volcano located in the northwest of Miyagi Prefecture. It consists of caldera of about 7 km in diameter and a lava dome cluster in its central part. Narugo-Nizaka tephra (Nr-N : SODA, 1989) is thought the biggest eruption that has formed about 90 ka (MACHIDA and ARAI, 2003). It consists of some fallout deposits composed of alternating pumice and ash beds, and an overlying nonwelded Nizaka pyroclastic flow deposit (ISHIDA, 1978. TSUCHIYA et al., 1997), but past reports indicated that there was no fallout deposits distribution area. The purpose of this report is to indicate that there is fallout deposits distribution area, and estimated that mode of eruptions.

According to SODA (1989), Nr-N is divided into five members. From the lower member, N1 is pumice fall deposit, N2 is alternating pumice and ash fall deposit, N3 is pyroclastic flow deposit, N4 is very fine glassy ash fall deposit, which is estimated to co-ignimbrite ash fall deposits, and N5 is layering ash fall deposit.

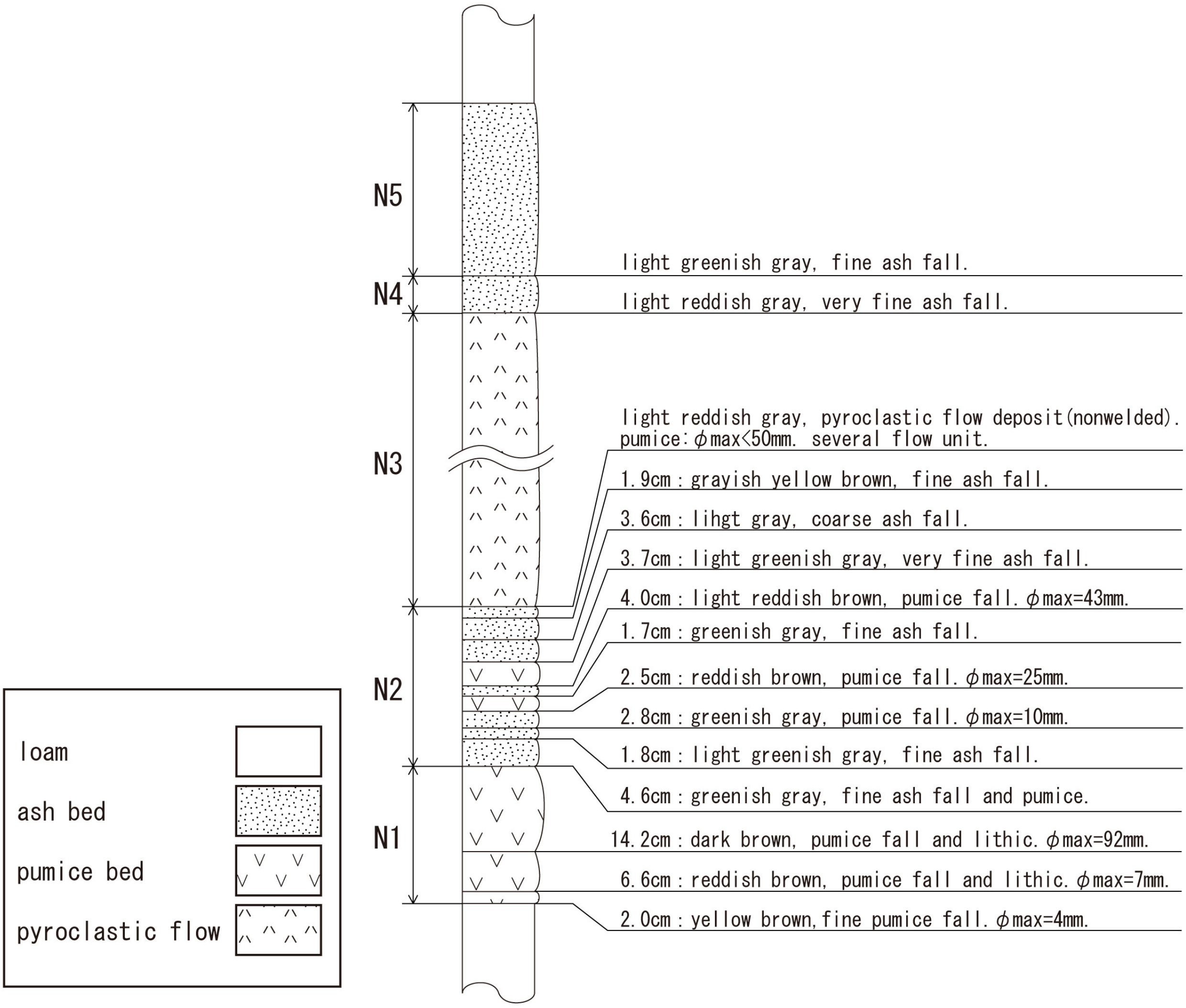
This report has taken up main fall deposit members N1, N2, and N5, and investigated with the sequence defined by SODA (1989), and confirmed that it was Nr-N based on the measured refractive index of volcanic glass and orthopyroxene.

Based on the field survey, we considered distribution axial direction. We considered from a relation between azimuth from Narugo volcano and maximum thickness of each tephra members outcrop. The distribution axis of N1, comes to an inclination of 75~90 degrees direction, N2 is 80~95 degrees direction. The distribution axis of N5 indicates bimodal, along 55~85 degrees and 105~130 degrees. On the other hand, there was no deposit which indicates a suspended period between N1 and N2, and distribution axis of N1 and N2 are similar. Because of this, we assumed that N1 and N2 are series of eruption. As a result of the reconsideration, the distribution axis of N1+N2 comes to an inclination of 80~105 degrees direction.

On the basis of these distribution axes, we made isopach maps. Synthesized isopach maps of N1+N2 and N5 shows good response to isopach map of MACHIDA and ARAI (2003). For reference, we calculated eruption volumes, using the 3D-modeling method by SUDO et al. (2007). The eruption volume of N1+N2 and N5 are estimated at 1.55 km^3 and 1.46km^3 respectively.

According to volcanic glass form and others, mode of eruption of each member is assumed as follows. Volcanic glass of N1 and N2, pumice type occupies a subject (90-70%). N1 and N2 are guessed at with Plinian eruption. Ash fall deposit part of N2 is being considered. There is a lot of volcanic glass of bubble-wall type more than N1 in N2 that suggests change in the eruption condition. There are few contents of volcanic glass in N5, therefore it's difficult to presume the mode of eruption. But the percentages of volcanic glass which is formed by quenched fragmentation of N5 is more than other members. N5 is suggested with Phreatomagmatic eruption.

Keywords: Narugo volcano, Narugo-Nizaka tephra, Nr-N, isopach map, pyroclastic fall deposit



Nr-N tephra schematic column

The 2011 Kurobe River earthquake of M5.4 with reference to deep crustal structure of the Hida mountain range

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Kurobe River earthquake

The Hida Mts. is located between Toyama and Gifu Prefectures and Nagano Prefecture, in central Japan. Many of mountain peaks rise above 3000 m. The Tateyama-Kurobe area is in the deepest part of the Hida Mts. Kurobe River runs through the eastern margin of Toyama Prefecture from the deepest part of the Hida Mts. down to the Toyama Bay.

The 2011 Tohoku earthquake of Mw9 induced Kurobe River earthquake swarm on March and October. A JMA magnitude of the largest event on October 4 was 5.4, which is call the Kurobe River earthquake in this presentation. Fig.1 shows epicenter distribution of the swarm and relative locations of the Tateyama Mt., the Kurobe River and Kurobe dam.

From scaling law between Mw and lengths of earthquake faults, a fault length of the M5.4 earthquake can be assumed to be 6 km, consistent with the swarm distribution. Assuming left lateral strike slip fault of a length 6 km, a fault width 3 km and a uniform slip 40 cm, we obtain crustal deformation in which amplitude of horizontal component of 3 cm to SE direction and vertical component of 5 mm subsidence.

Tateyama-Midagahara volcano

The Tateyama-Midagahara volcano (36.571N, 13.590E, Elevation 2.6 km) is one of 110 active volcanoes listed in JMA Catalogue for volcanic warnings and volcanic alert. In the past decade, there were volcanic plume activity in 2006, sulfur combustion forming sulfur flows in 2010 and reactivation of plume activity in 2014 (JMA Web for volcanic warning). Research group of Tokyo Institute of Technology conducted audio-frequency magnetotelluric survey in 2013 to find a conductive layer suggesting hydrothermal reservoir a few hundred meters below surface (Seki et al., 2015).

Deep crustal structure below Tateyama-Kurobe area

Analyzing refraction/reflection experiment data along a 180 km long profile between Agatsuma in Gunma and Kanazawa in Ishikawa Prefectures passing through the Tateyama-Kurobe Alpen route, Takeda et al. (2004) obtained the crustal structure below the Hida Mts. At the time of the 1996 Joint Geophysical Research in the Hida District, we operated temporary dense seismic network of seismographs installed every 1 km along the Tateyama-Kurobe Alpen Route. Analyzing two sets of data, Matsubara et al. (2000) successfully obtained beautiful tomographic model Fig.2 of P wave velocity below the Tateyama-Kurobe area. Fig.2 shows a reservoir of partially melted magma at depths from surface down to 15 km, where P and S wave velocities are 5 km/s and 2.5 km/s, respectively.

Above results suggest that a part of fluid rising up from magma reservoir becomes fluid reservoir at depths a few hundred meters below Tateyama-Midagahara and another part infiltrates into a fault to induce earthquake at the point indicated by arrow in Fig.2.

Concluding comments

It seems to be much dynamic and attractive to tackle volcanic activity, earthquake and deep structure of Tateyama-Kurobe Geopark area together with geological history in a single framework.

The rupture area of the 1984 Western Nagano Prefecture earthquake was about 10 km away from Ontake volcano that erupted in 2014. That of the 2011 Kurobe River earthquake was about 5 km away from

Tateyama-Midagahara volcano. These showed that, for the purpose of protection of tourists, volcanic and seismic activities should be investigated simultaneously.

Fig.1 Distribution of epicenters of earthquake swarm on March and October, 2011, plotted on basic map due to GSI Web Site. Data selection by TSEIS of ERI, University of Tokyo with earthquake parameters of JMA.

Fig.2 E-W cross section of P wave velocity below the Tateyama-Kurobe region (Matsubara et al., 2000). A red arrow indicates location of the Kurobe River earthquake.

Keywords: Tateyama-Midagahara Volcano, Kurobe River, induced earthquake, crustal structure, magama reservoir

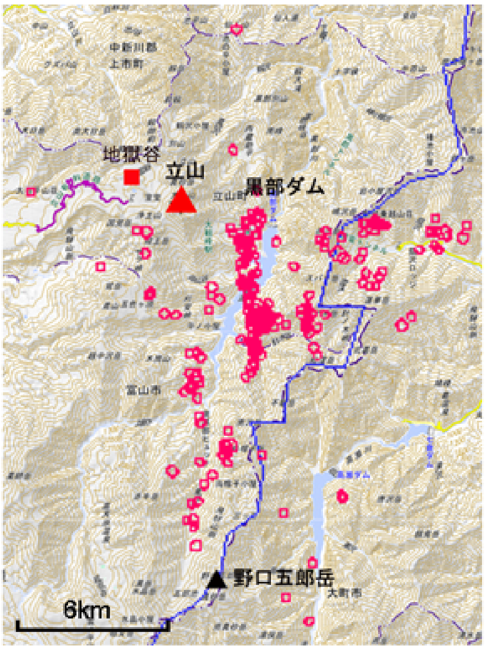

Fig1

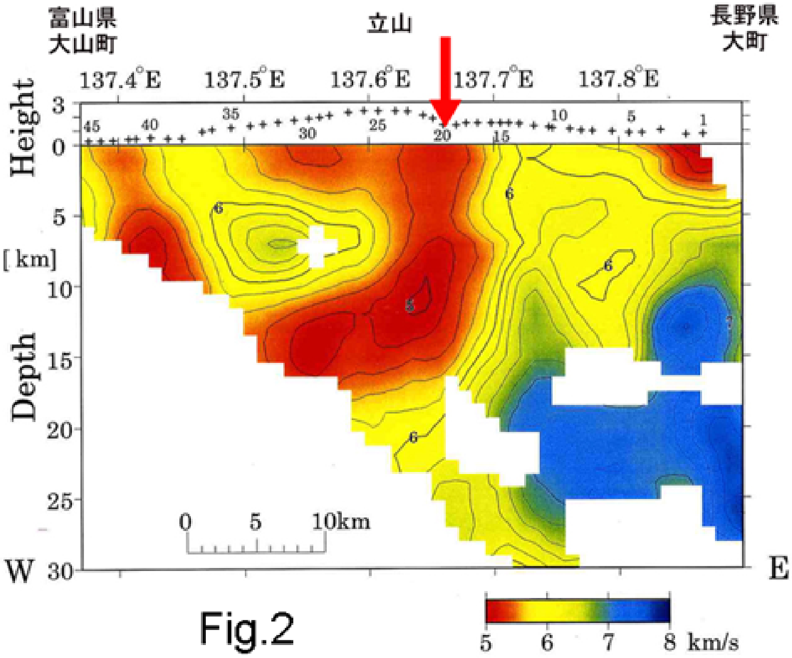

Fig.2