

Eruption History and Future Scenario of Sinabung volcano, North Sumatra, Indonesia

YOSHIMOTO, Mitsuhiro^{1*}; NAKADA, Setsuya²; ZAENNUDIN, Akhmad³; PRAMBADA, Oktory³; HOKANISHI, Natsumi²; TAKAGI, Natsuko²; HENDRASTO, Muhamad³; IGUCHI, Masato⁴

¹Faculty of Science, Hokkaido University, ²Earthquake Research Institute, University of Tokyo, ³Center for Volcanology and Geological Hazard Mitigation, Indonesia, ⁴Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

Sinabung Volcano is an andesitic stratovolcano located 40 km northwest of Lake Toba, North Sumatra. The activity began after the latest caldera-forming eruption of Toba Lake (ca. 74ka). The eruption history can be divided into two stages (old and young stages) based on topographical and geochemical features. The edifice is characterized by multiple thick lava flows/domes, and their collapsed materials of block-and-ash flow and associated surge deposits. The lava spine is located at the southern end of one of the summit craters which trend in N-S. Pumice-fall deposits by relatively large explosive eruptions, such as plinian-to subplinian types, were not recognized. The last magmatic eruption before 2010 occurred during 9 to 10th century, whose products are mainly pyroclastic-flow deposits, distributed in the SE slope.

The present activities began with phreatic events in August and September 2010. It resumed its activity in September 2013 with phreatic events. After the repeated phreatic to phreatomagmatic events, lava appeared in the summit crater in late December and started its partial collapse on 30 December. Several tens collapses occurred everyday in January 2014. Those pyroclastic flows descended on the SE slope of the volcano and traveled 4.5 km in maximum.

Lavas of the volcano are basaltic andesite to andesite in composition, and andesitic lavas contain hornblende phenocrysts. Although old lava have a SiO₂ range similar to young lavas, the old lava are more enriched in K₂O than the young lava. The lava spine is highly enriched in SiO₂ and extremely depleted in Na₂O, a result of high alteration by volcanic gases, suggested by the mineralogical features. Bulk composition of 2010 ash seems to be intermediate between the young lava and the altered lava spine. In contrast, pumice of 2013 eruption has a similar composition of juvenile materials of 9-10th eruption.

Before the 2013-2014 events, highly possible scenario for future eruption have been proposed the similar case of lava-dome eruptions at Unzen, Japan, in 1991-95 and at Soufriere Hills, Montserrat, West Indies, in 1995-present, based on the eruption history. The present eruption at Sinabung follows the proposed scenario of the highest probability.

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Keywords: Indonesia, Sinabung, volcanic eruption, eruption history, Scenario, pyroclastic flow

Petrological study of monogenetic volcanoes in the fore-arc region of the northern Kamchatka Peninsula

NISHIZAWA, Tatsuji^{1*}; CHURIKOVA, Tatiana²; GORDEYCHIK, Boris³; ISHIZUKA, Osamu⁴; NAKAMURA, Hitomi¹; IWAMORI, Hikaru⁵

¹Department of Earth and Planetary Sciences, Tokyo Institute of Technology, ²Institute of Volcanology and Seismology Far East Division, Russian Academy, ³Institute of Experimental Mineralogy, Russian Academy, ⁴Research Core for Deep Geological Environments, AIST, ⁵Japan Agency for Marine-Earth Science and Technology

The western part of the Pacific Plate is subducting under the Okhotsk Plate along Kuril-Kamchatka Trench, and the northern part of it is subducting under the Bering Sea Plate with high obliquity along the western Aleutians arc. The three plates form the Aleutian-Kamchatka triple junction (Eichelberger *et al.*, 2013). The northern edge of the Pacific Plate is separated from Bering Sea Plate by transform fault, and the mantle edge beneath the Kamchatka Peninsula is thought to be open towards the Bering Sea.

There are at least 29 active volcanoes in the Kamchatka Peninsula. From the east to the west, arc volcanism on the Kamchatka Peninsula forms three zones parallel to the Kamchatka trench: the Eastern Volcanic Front (EVF), the Central Kamchatka Depression (CKD) including Klychevskaya Volcano Group (KVG) where the large volcanoes concentrate, and the Sredinny Ridge (SR) in the back arc side.

Along EVF, the straight volcanic chain is terminated around 55°N (near the Kizimen volcano), and in further north the volcanic chain seems to deflect toward KVG corresponding to deeper depth of subducting slab. However, monogenetic volcanoes on the northward extension of the EVF exist and were studied in 1960s, called 'Kumuroch range' (Fedororenko., 1969). The present-day slab depth beneath the monogenetic volcanoes is about 60km (Gorbatov *et al.*, 1997), and the crustal thickness is about 20-30km (Levin *et al.*, 2002). These volcanic rocks were reported as basalt to andesite, having relatively high MgO content (~11.8 wt. %) and low FeO/MgO ratio (<1.0) (Uspensky and Shapiro., 1984). In summer 2013, we have identified 15 monogenetic volcanoes in this area (hereafter 'East Cone volcanic group', EC) by using stereogram, and had investigated 8 volcanoes by using a helicopter.

In this study, we aim to reveal the origin of the EC lavas. For this purpose, we have first examined mineral assemblages under optical microscope and analyzed the whole rock major element compositions by XRF. All 16 samples are classified as basalt or basaltic andesite, of which the two lavas contain xenoliths, and one sample oxidized to red. The rocks exhibit porphyritic to seriate texture, containing plagioclase, clinopyroxene, olivine, opaque minerals, although, the proportion of minerals varies from sample to sample. The silica contents of all samples are over 50 wt. %, with the FeO/MgO ratio less than 2, indicating relatively undifferentiated characteristics.

In comparison to the typical island arc basalts having a similar silica content, the MgO contents of the EC lavas are higher by ~4 wt. %. Accordingly, the EC lavas are similar to or classified into high-Mg andesite, which is considered to be generated by melting of relatively hydrous mantle (as an example, unsaturated with H₂O, 1.0GPa, 1100-1250 °C, saturated with H₂O, 1.5GPa, 1030-1150 °C) (Tatsumi., 1995; 2003).

The EC lavas scarcely include orthopyroxene, on the other hand, volcanic rocks of KG include orthopyroxene (Churikova *et al.*, 2013). Mantle xenoliths from the Bezymianny volcano of KG is reported to be spinel harzburgites (Ionov *et al.*, 2013). Combining these constraints, we discuss a regional variation in mineral assemblage and H₂O content in source mantle, H₂O content in the primary magma, and the crystallization temperature and pressure of the magmas.

By comparing the petrological characteristics of the EC lavas with those from other regions (e.g., KG), clear constraints on the relationship between magma genesis and the tectonic setting are expected to be imposed.

Keywords: arc, high-Mg andesite, Kamchatka Peninsula, triple junction

Geology and petrology of Taisetsu volcano group, Japan; Evolution of magma and long-term time variation of eruption rate

ISHIGE, Kosuke^{1*}; NAKAGAWA, Mitsuhiro¹; MATSUMOTO, Akikazu²

¹Department of Natural History Sciences, Graduate School of Science, Hokkaido University, ²Geological Survey of Japan, National Institute of advanced Industrial Science and Technology

Taisetsu volcano group locates at the northern part of the Taisetsu-Tokachi volcanic chain, which is situated at the southern end of Kuril arc. The volcano group started its activity ca. 1 Ma and is composed of andesitic lava domes and stratovolcanoes. Although previous studies (eg., NEDO, 1990; Katsui, 1979) revealed the outline of structure and eruptive history of the group, detail chronological and petrological studies have not been carried out. We have revealed the volcano stratigraphy and petrological features of the whole area of the volcano group. In addition, K-Ar ages of representative samples are also determined. Based on these data, we focus on the temporal change of eruption rate and magma types during 1 My in the volcano group.

According to the stratigraphy, location of eruption centers, mode of eruptive activity and petrological features, the activity of the volcano group can be divided into four major stages, as follows. Stage 1(1.0 ~0.75Ma): Fluidal andesite lava were effused from several eruption centers to form flat-shaped volcanic edifices which are distributed in N-S direction. Their total estimated eruptive volume is 26km³(DRE). Stage 2: It can be subdivided into sub-stage 2-1 (0.6Ma) and 2-2 (0.35 ~0.05Ma). Eruptive lavas of the former sub-stage are mostly covered by younger deposits. Detail structure of the edifice and the distribution of deposits have not been clear. The sub-stage 2-2, is further subdivided into central and western group according to the differences in mode of activity and location of eruption centers. The total estimated eruptive volume of stage 2 is 23km³. Stage 3(ca. 30 ka): The stage is characterized by most explosive eruptions in the volcano group, resulting to the formation of a plinian column and related pyroclastic flows. These activities formed the Ohachidaira caldera with 2 km in a diameter. The total eruptive volume is estimated to be 13km³. Stage 4 (ca. 30 ka - present): Main eruption centers moves to the southwestern part of the caldera to form several stratovolcanoes and lava domes. The total eruptive volume of stage 4 is 10km³. Based on the ages and estimated eruptive volume, the magma discharge stepdiagram of the volcano group is created to discuss a temporal change of magma discharge rate. The eruption rate of each stage is as follows; >0.07km³/ky for stage 1, >0.01km³/ky for stage 2-1, >0.06km³/ky for stage 2-2, >0.33km³/ky for stage 3, >0.33km³/ky for stage 4. According to the stepdiagram, the period from 0.7 to 0.4 Ma could be characterized by extremely low eruption rate and/or the presence of dormant stage.

Petrological features of the ejecta of Taisetsu volcano group can be distinguished among stages. All of the rocks are andesite and dacite, often containing mafic inclusions. These rocks contain plagioclase, clinopyroxene, orthopyroxene and Ti-magnetite as phenocrysts, associated with minor amounts of olivine, and quartz phenocrysts in some rocks. Although the rocks of stage 1 do not contain hornblende phenocrysts, those of stage 2 and 3 usually include hornblende phenocrysts. However, there rarely exist hornblende phenocrysts in the rocks of stage 4. The whole-rock SiO₂ contents range from 56.4 to 69.1 wt.% for host rocks and from 52.7 to 57.4 for the inclusions. Almost all the rocks are defined as medium-K in SiO₂ - K₂O and CA types in SiO₂-FeO/MgO diagrams, respectively. The host of the rocks from stage 1 is characterized by high Zr contents, compared with the rocks from other stages, whereas Zr contents in the mafic inclusions in the rocks from stage 1 are the same as those from other stages. Considering Zr contents and occurrence of hornblende phenocryst in andesite, magma type had changed largely during the possible long dormancy from 0.7 to 0.4 Ma. This would be related to the tectonic change at the junction between NE Japan and Kuril arcs.

Keywords: Volcano, Eruption rate, Formation history, Taisetsu, Geology and petrology, Transition of magma

Reconstruction accuracy of eruptive sequence inferred from the pyroclastic fall deposits of the Asama-Maekake volcano

YASUI, Maya^{1*}

¹Dept. of geosystem sciences, Nihon University

The pyroclastic fall deposits of the Asama-Maekake volcano, such as A (1783AD), B' and B (12th century), and C (4th century), are mainly composed of pumice layers. On the other hand, ash fall derived from the recent vulcanian eruptions (e.g., 2004 and 2009 eruptions) is too small in scale to be preserved as a geologic unit. Ash particles from such small-scale eruptions are mainly lithic fragments originating from solidified lava in a shallow level of the conduit. After the 1783 eruption, repeated vulcanian eruptions have formed ash and soil mixtures on the flank of the volcano. Similar ash and soil mixtures are also recognized beneath A, B, C, and D pyroclastic fall deposits, respectively. These ash and soil mixtures contain lithic fragments as the ash component, indicating that vulcanian eruptions occurred repeatedly in the period between large-scale eruptions, similarly to the period after the 1783 eruption. Lithic ash layers are also interbedded with pumice fall layers of B', B, and E pyroclastic fall deposits. There seem to be some cases of intermittent vulcanian and sub-plinian eruptions in the course of the large-scale eruption.

In the case of the 1783 eruption, detailed reconstruction of the eruptive sequence is possible on the basis of correlation between the stratigraphy of the eruptive products and old documents. The large-scale sub-plinian eruption is considered to be associated with the formation of a pyroclastic cone in a proximal area owing to vigorous fountaining. Subsequently, large-scale clastogenic lava flows are generated throughout its climactic eruption. On the other hand, little information is available for eruptions before 1783 because of limited exposure and few old documents. Although the reconstruction accuracy for the eruptions in the 12th century is not as good as that for the 1783 eruption, these eruptions might have occurred with a different sequence from the 1783 eruption. Intermittent events of ash and pumice fall occurred in the initial stage of these eruptions. Phreatomagmatic eruption also occurred in the early stage of the 1128 eruption, resulting in a B' pyroclastic fall deposit. The existence of many units of pyroclastic flows in the 1108 eruption indicates that pyroclastic flow occurred on multiple occasions. Since the stratigraphic relationship between the B pyroclastic fall and these pyroclastic flows is unclear, the sequence of the eruption is still in question. Furthermore, little information is available for eruptions predating the 12th century.

Comparative study of the distributions of pyroclastic fall deposits using isopach maps reveals that some fall units from B' and B are larger in scale than that of the climactic pyroclastic fall deposit of the 1783 eruption. In addition, the A' pyroclastic fall deposit is estimated to be comparable to or smaller than the preclimactic fall unit of the 1783 eruption. Although the isopach maps of A, B', B, C, and E could be prepared, the accuracy of the isopach maps for the C and E pyroclastic fall deposits is insufficient. The preparation of an accurate map is difficult for deposits of older age. Consequently, at this point, the 1783 eruption is the only example in which the temporal variation in eruptive style and in eruptive volume can be discussed with high accuracy in the history of the Asama-Maekake volcano.

Polybaric crystallization of H₂O-saturated island arc low-K tholeiite magmas: A case study of the Izu-Oshima volcano

HAMADA, Morihisa^{1*} ; OKAYAMA, Yuko² ; KANEKO, Takayuki³ ; YASUDA, Atsushi³ ; FUJII, Toshitsugu⁴

¹Japan Agency for Marine-Earth Science and Technology, ²National Museum of Emerging Science and Innovation, ³Earthquake Research Institute, University of Tokyo, ⁴Crisis and Environment Management Policy Institute

Introduction: The H₂O concentration of pre-eruptive melts, particularly that of primitive melts, provides information on the *P-T* conditions of their generation, their differentiation pathways, and their potential explosivity of eruptions. Consensus with regard to the H₂O concentration of island arc low-K tholeiitic magmas (melts) remains elusive. We investigated conditions of their crystallization differentiation, particularly the H₂O concentration in melts, using geochemical data of volcanic rocks from Izu-Oshima volcano in the Izu arc, along with the results of hydrous melting experiments.

Geochemistry and petrology of volcanic rocks: We selected 68 aphyric volcanic rocks which exhibit multiply saturated liquid compositions of the Izu-Oshima volcano. Among them, two magma groups are distinguished by the K/Zr ratio, a lower-K subgroup (K/Zr<60) and a higher-K subgroup (K/Zr≥60). In this study, we focus on the higher-K subgroup liquids. Two endmember trends, referred to here as a higher-Al/Si trend and a lower-Al/Si trend, have been distinguished in the higher-K subgroup liquids. All the liquids are bracketed by these two endmembers, and thus may be mixtures of the two endmembers or may have been derived under intermediate conditions between those responsible for the two endmembers. An experimental study by Hamada and Fujii (2008, *Contrib. Mineral. Petrol.*) suggests that the higher-Al/Si and lower-Al/Si trends can be reproduced by upper crustal crystallization differentiation of primitive basalt under moderately hydrous (~3 wt % H₂O) and almost dry conditions, respectively.

Hydrous melting experiments on island arc low-K tholeiite magmas: Island arc low-K tholeiite magma is characterized by presence of Ca-rich plagioclase (An≥90), with Ca-poor rim (~An75). Hydrous melting experiments on two volcanic rocks from the Izu-Oshima volcano, MA43 and MA44 (MgO~5 wt %), were conducted at 250 MPa to constrain the origin of Ca-rich plagioclase (Hamada and Fujii 2007, *Geochem. J.*). MA43 and MA44 represent less differentiated liquid compositions on the higher-Al/Si and lower-Al/Si trends, respectively. In the melting experiments on MA43, plagioclase crystallized as the liquidus phase at all H₂O content (1~6 wt % H₂O), and anorthite content of the plagioclase increased from ~An80 under nearly dry conditions to An≥90 with ≥3 wt % H₂O in melt. In the melting experiments on MA44, plagioclase crystallized as the liquidus phase under low-H₂O (≤2 wt %) conditions, but augite replaced plagioclase as the liquidus phase with more H₂O in melt. Anorthite content of plagioclase increased from about An70 under nearly dry conditions to An80 with ~4 wt% H₂O in melt. Increases in anorthite content of plagioclase crystallized from the MA44 melt were suppressed compared with plagioclase crystallized from the MA43 melt. In short, Ca-rich plagioclase (An≥90) can be crystallized from melts on the higher-Al/Si trend with ≥3 wt % H₂O, but cannot be crystallized from melts on the lower-Al/Si trend with any H₂O. Ca-poor rim (~An75) cannot be crystallized from melts on the higher-Al/Si trend, but can be crystallized from melts on the lower-Al/Si trend.

Summary: Geochemical variations in the liquids from the Izu-Oshima volcano are bracketed by two endmember trends, namely, the higher-Al/Si and the lower-Al/Si trends. Origins of the higher-Al/Si and the lower-Al/Si trends can be explained by crystallization differentiation under moderately hydrous conditions (~3 wt% H₂O) and almost dry conditions, respectively. We propose that polybaric crystallization of H₂O-saturated melts, at a depth range between the ~4-km-deep magma chamber (~3 wt% H₂O) and near surface level (nearly dry) beneath the Izu-Oshima volcano, is a ubiquitous feature of island arc low-K tholeiite magmas.

Keywords: Island arc low-K tholeiite, Volcanic front, Ca-rich plagioclase, Izu-Oshima volcano

The change time from magmatic to phreatomagmatic eruption, in the Hachodaira caldera eruption at Miyakejima Volcano

OIKAWA, Teruki^{1*} ; GESHI, Nobuo¹

¹GSI, AIST

The Miyakejima volcano formed the caldera in 2000. This volcano erupted Hachodaira Scoria and Hachodaira Ash at ca.3ka of Hachodaira caldera collapse. Many plant fossils (*Miscanthus* sp.) are recognized in Hachodaira Scoria and Ash. Based on plant fossils in these tephras occurrence, deposition late of soil in the Miyakejima volcano, and form of the boundary of Hachodaira Scoria and Ash, The change time from magmatic eruption (Hachodaira Scoria eruption) to phreatomagmatic eruption (Hachodaira Ash) is under 1 year, probably it is several days or less. Thus, there was no time gap almost between magma eruption and phreatomagmatic eruption. This eruption style change can be explained such as 2000 eruption (Geshi and Oikawa,2008:JVGR) as follows. The altitude of the summit part approached the sea level by caldera collapse; as a result, phreatomagmatic eruption occurred.

Keywords: volcano, caldera, Miyakejima, eruption, *Miscanthus*

Pumice deposits of the pre-Ofunato stage distributed in northwest of the Miyake-jima volcano, northern Izu-Bonin Arc

NANRI, Shohei^{1*} ; SUZUKI, Takehiko²

¹Graduate student, Tokyo Metropolitan University, ²Tokyo Metropolitan University

Miyake-jima Island, a volcanic island of the northern Izu-Bonin Arc, is located in the northwestern Pacific Ocean, approximately 180 km south of Tokyo. A pale-orange-tuff layer had been reported by Issiki (1960) on coastal cliff in the northwestern part of the island. The aim of this study is to clarify (i) distribution, (ii) stratigraphic position, (iii) sedimentary structure, (iv) petrological features, and (v) mineralogical features, for this pyroclastic deposit in more detail. The layer was re-defined as "Miyake-jima Ofunato Pumice deposit: OFP". The OFP is distributed from western to northern parts of the island. The OFP exists below the Aira-Tn tephra, erupted at 30 ka. The sedimental facies of OFP deposits suggest it formed as a pyroclastic flow deposit.

The relation between K₂O and FeO concentrations in the OFP is characterized by higher FeO wt.% and lower K₂O wt.%. Tsukui et al. (2006) and Saito & Miyairi (2008) showed that the chemical trends in the volcanic products of forearc of Izu-Bonin Arc such as Izu-Oshima and Hachijo-jima are characterized by high FeO wt.% and low K₂O wt.%, and those of the backarc Izu-Bonin Arc such as Nii-jima and Koze-shima shows low FeO wt.% and high K₂O wt.%. Consequently, chemistry of the OFP suggests that it was originated from forearc of Izu-Bonin Arc.

This paper concludes that the activities of the Miyake-jima volcano around 30 ka are characterized by a production of pumice by the eruption at the northwestern part of the present island. The current stage of this study, it is not possible to discuss the source vent of the OFP in detail and specify the type of the volcanic eruption produced the OFP. In future, we attempt to find a clue to account for these two problems by the detailed study on the OFP with referring to its facies like a pyroclastic flow deposits.

Keywords: Miyake-jima volcano, Pumice, Miyake-jima Ofunato Pumice deposit, Northern Izu-Bonin Arc

Formation process of a volcanic island during the 2013-2014 eruption at Nishinoshima, Ogasawara, Japan

MAENO, Fukashi^{1*} ; NAKADA, Setsuya¹ ; KANEKO, Takayuki¹

¹Earthquake Research Institute, Univ. Tokyo

New volcanic islets created by submarine eruptions are often observed around Japanese Islands. However, in most cases, such new islets are disappeared by wave erosion in short periods. To make a new volcanic island remaining for a long time, an amount of lava flows must occur and reclaim land from the sea. However, such relatively large-scale lava eruptions rarely occur. Therefore, the very initial stage of the formation process of a volcanic island has been poorly understood.

The submarine eruption off Nishinoshima, Ogasawara, has created a new volcanic islet since Nov 2013. The lava flow eruption continues for more than a few months, and the islet keeps growing. This eruption will give an opportunity to understand the birth and growth of a new volcanic islet. We studied variation of eruptive styles and sequences of this 2013-2014 eruption at Nishinoshima based on airborne observations and publicized aerial and satellite images (taken by JCG, GSI, and JAXA).

Nishinoshima forms a part of summit crater rim of a huge submarine volcano. The 2013-2014 eruption occurred inside the summit crater about 400 m off Nishinoshima with a depth of dozens of meters. In the first stage, Surtseyan eruptions repeated due to seawater entering a main crater of an islet. With the growth of the islet, the main crater was dried up and the eruption style changed to Strombolian with a scoria cone formation and lava flows that continuously effuse from the main crater over a few months. Lava flow front is brecciated by rapid cooling, or auto-brecciated, and eventually reclaimed the foreshore from the sea. The lava flows are then branched many times and extended to almost all directions. The continuous activity of Strombolian with lava flows suggests that magma is stably supplied from the deeper part of conduit.

Based on the change of outline of the islet and bathymetry data before the eruption, volume and discharge rate of lava flows are estimated. For the first 2.5 months by early Feb 2014, the volume of lava flow is estimated at about 6 M m³. The discharge rate is estimated at 0.5-1*10⁵ m³/day with some fluctuations. This discharge rate is almost the same as that estimated for lava effusion in the 1934-1935 eruption at Showa Iwojima, southern Kyushu (1*10⁵ m³/day; Maeno and Taniguchi, 2006), which is one of the youngest remained volcanic islands in Japan. The volume of the 2013-2014 eruption is so far 1/4 of the total volume (24 M m³) of the last 1973-1974 eruption, in which the volume of the last eruption was estimated based on bathymetry change before and after the eruption. The eruptive sequence and growth rate of the islet in 2013-2014 is different from the last eruption. This is probably because the eruption began at shallower depth than the last eruption. At the time of early Feb 2014, erosion signatures on lava flows are little, so that the new island is expected to further grow.

Keywords: Nishinoshima, volcanic island, lava flow, Surtseyan eruption, Strombolian eruption

Petrological characteristics of volcanic materials ejected during 2012-2013 explosive events on Ioto Island

IKEHATA, Kei^{1*} ; TAMURA, Tomoya²

¹Faculty of Life and Environmental Science, University of Tsukuba, ²Graduate School of Life and Environmental Sciences, University of Tsukuba

Ioto is an active volcanic island (8.5km long in NE-SW and 4.5km wide) located about 1250km south of central Tokyo. Since early February 2012, small explosive eruptions have repeatedly occurred at the Old Crater (Million Dollar Hole) in the western part of the island (JMA, 2013). Four (February 2012, March 2012, February 2013 and April 2013) ejected mud materials collected in the vicinity of the crater consist of free crystals (plagioclase, clinopyroxene, olivine, and Fe-Ti oxides), relatively fresh volcanic glass, altered volcanic glass, lithic fragment, altered lithic fragment and pyrite aggregate (Ikehata and Tamura, 2013). Among the mud samples, there is little difference in component of grains except for high abundance of altered lithic fragment in the mud ejected in February 2012.

Detailed SEM/BSE image observation of the relatively fresh volcanic glasses show that even these fresh glasses have pitted alteration and hydration features. The extent of hydration could be different among volcanic glass shards in geothermal field like Ioto because hydration rate depends on chemical compositions of volcanic glasses and groundwater, and soil temperature. To eliminate such hydration effects, heating (400 °C-12h) is conducted for the relatively fresh volcanic glasses before analyzing. As a result of the chemical analysis, all of these volcanic glasses are trachytic, and their chemical compositions are homogeneous within the analytical error. In conclusion, no juvenile materials existed in the mud samples, suggesting these explosive events were not phreatomagmatic but phreatic eruption.

We would like to thank members of JMSDF Ioto Air Base weather team for sampling around the Old Crater and providing information on the studied area. Ministry of Defense, JMA and NIED are also thanked for their cooperation.

Keywords: Ioto Island, the Old Crater, mud, volcanic glass, phreatic eruption

Compositions of minerals in volcanic products from pre- and the early stage of Aso-4 large-scale pyroclastic flow

KUROKAWA, Kiyoshi¹ ; YAMASAKI, Hideto¹ ; HASENAKA, Toshiaki^{1*} ; MORI, Yasushi²

¹Grad School Sci. & Tech., Kumamoto Univ., ²Kitakyushu Museum of Natural and Human History

Formation of Omine scoria cone, Takayubaru lava flow, and Oyatsu pumice flow are a series of volcanic events just before and after the large-scale Aso-4 pyroclastic eruption. Compositions of volcanic products change from 62-66 SiO₂ wt.% for Omine scoria, 63-66 SiO₂ wt.% for Takayubaru lava, to 67-69 SiO₂ wt.% for Oyatsu pumice. The difference between Omine-Takayubaru compositional trend and Oyatsu trend is small but evident (Yamasaki et al., 2013). Common phenocryst assemblage is plagioclase, orthopyroxene, clinopyroxene, and opaque minerals. In addition, Omine scoria and Takayubaru lava contain hornblende microphenocrysts, whereas Oyatsu pumice contains phenocrysts of hornblende. Most plagioclase characteristically shows sieve texture among Omine-Takayubaru samples. Such texture is not so common among Oyatsu pumice samples. We analyzed these minerals using EPMA in order to characterize the change in magma supply system that lead to large-scale pyroclastic eruption.

In response to different compositional trends observed between Omine-Takayubaru and Oyatsu samples, different mineral compositions are also found. Plagioclase phenocrysts in Omine-Takayubaru samples are An50-An60 with uni-modal peak, where as those in Oyatsu samples are An37-An56 with three peaks. Slight difference in Mg# are also found between orthopyroxene, clinopyroxene, and hornblende of Omine-Takayubaru and those of Oyatsu samples.

Estimated temperature for Omine scoria using Wells (1977) pyroxene thermometer is 950 °C, and dry viscosity is 10^{5.6} Pa • s. That for Tamaraigawa lava (SiO₂=61 wt.%) extruded before Aso-2 pyroclastic eruption was reported as 1120 °C and 10^{3.9} Pa • s, respectively, by Kobayashi (2013). The difference in viscosity is reflected by different aspect ratio, i.e. 100 m thick and 7 km long for Takayubaru lava flow, and 10 m thick and 10 km long for Tamaraigawa lava flow.

Sieve texture and microphenocrysts in Omine scoria and Takayubaru lava make an important restriction for making models of magma supply system before and after the large-scale pyroclastic eruption. If sieve texture suggests melting process of plagioclase, it indicates temperature ascent and/or water vapor pressure increase. In contrast, growth of hornblende microphenocryst suggests temperature drop and/or water vapor pressure increase. Omine-Takayubaru samples do not contain mafic inclusions and mafic minerals with reverse zoning, thus possibility of magma mixing and temperature ascent is small. The change in physico-chemical condition in Aso-4 magma supply system is yet to be solved.

Keywords: Aso-4 pyroclastic flow, Takayubaru lava, Omine volcano, lava flow

Forming process of Minamidake stratovolcano, Sakurajima, inferred from paleomagnetic age and volume of lava flows

MIKI, Daisuke^{1*}

¹DPRI, yoto University

A paleomagnetic measurement was carried out on the Arimura lava, which consists uppermost part of the main body of Minamidake stratovolcano, Sakurajima volcano, Kyushu, Japan. A mean paleomagnetic direction, $D=4.0^{\circ}$ $E I=40.5^{\circ}$ down, was obtained from the Arimura lava. By comparison between measured paleomagnetic direction and the paleo-secularvariation of geomagnetic field, the age of the Arimura lava was estimated as about 3.1-2.7 ka, moreover the age of the Kannonzaki lava lying beneath the Arimura lava, was thought as about 3 ka. These two lavas are considerable to be formed by a sequence of intermittent eruption during several hundred years at around 3 ka. The volumes of individual lava that extruded in recent 4,000 years were estimated. The main body of Minamidake stratovolcano had grown rapidly at around 3 ka, since estimated lava volume. The volume of the Nagasakihana lava erupted in 764-766 AD was estimated as about 0.8km^3 . The scale of 764-766 AD eruption may be greater than previously thought. The long-term magma effusion rate during historic time, particularly recent 240 years, was estimated as larger than earlier.

Morphology of microlite -projections of plagioclase microlite-

SANO, Kyohei^{1*} ; TORAMARU, Atsushi² ; WADA, Keiji³

¹Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, ²Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, ³Hokkaido University of Education at Asahikawa

At Tokachi-Ishizawa (TI) rhyolite lava, Shirataki, Hokkaido, northern part of Japan, the interior structure transition can be observed, from the outer obsidian layer to the inner rhyolite layer. Thus TI lava is an appropriate target field for correlating textural characteristics with lava interior structure. In order to obtain insights into the magma ascent and outgassing process of viscous magma, we have analyzed oxide microlites of TI rhyolite lava, suggesting that dominant outgassing process is ductile permeable development (Sano et al., 2013 JpGU meeting). However, we have not examined the morphology of microlite. Morphology of crystal is considered to reflect the effective undercooling of the melt and provide the constraint for ascent process and water exsolution processes. In this study, we focused on the morphology of microlites, especially projections of plagioclase microlites. The projections mean localized growth of crystal from plagioclase surface.

In Shirataki, aphyric rhyolite lavas erupted ca. 2.2Ma and composed of 10 flow units. The TI lava is about 50 m in height and stratigraphic sequences from the bottom are a obsidian layer region, a boundary bounded region of obsidian and rhyolite, and rhyolite layer region. The obsidian layer region consists of a single vesicle-free obsidian about 7 m high. The rhyolite layer region consists of rhyolite layers with variable vesicularity, crystallinity and characteristic scales in layer thickness. The boundary banded region, which is located between the obsidian and rhyolite regions, consists of thin obsidian (<10mm in width) and rhyolite. In this study, we define the obsidian and rhyolite based on the differences in appearance of hand specimens and rock texture. Rhyolite has perlitic cracks in the glass and contains some amounts of crystalline materials, namely, spherulite and lithophysae. In boundary banded region, the fraction of obsidian decreases toward rhyolite layer region.

From the examination by scanning electron microscope (SEM) for thin sections from obsidian layer region, boundary banded region and rhyolite layer region, we found the projection texture in all samples. We measured projection length and number density (Nv) of plagioclase microlites for obsidian and rhyolite layer regions. The measurement results show that plagioclase microlites in obsidian and rhyolite layer regions indicate the similar number density. Nv for obsidian layer region is $1.8 \times 10^{11} - 3.5 \times 10^{11} [m^{-3}]$ and $8.2 \times 10^{10} - 3.0 \times 10^{11} [m^{-3}]$ for rhyolite layer region, respectively. However, the length of projection is remarkably different between two regions. The mean values are $2.3 \mu m$ in obsidian layer region, and $8.7 \mu m$ in rhyolite layer region. The transition of mean length can be observed in boundary layer region.

Since the difference of projection length reflects the growth rate ($G [m/s]$) and growth time ($t [s]$) according to the theory of crystal growth (Keith and Padden, 1963; Lofgren, 1971; Rao, 2002), we can estimate the degree of effective undercooling at the formation time of projections. Under the assumption that G is constant for the time, the length of projection can be given by Gdt . Assuming the constant growth rate and growth time, the difference in projection lengths indicate that in growth rate, namely, the undercooling. Using experimental values for growth rate and undercooling, it is found that the rhyolite layer region experiences higher undercooling than obsidian layer region by 30 – 70 K. The projection can be formed after the nucleation of plagioclase microlite, which indicate the similar number density in obsidian and rhyolite layer region. Thus projections reflect the different undercooling after the nucleation of microlites. Based on the quantitative analysis of crystal morphology of microlites, we can obtain the insights into the magma ascent process that rhyolite layer region experienced higher undercooling than obsidian layer region.

Keywords: textural analysis, obsidian, rhyolite, lava, Shirataki

Differentiation process of arc magmas revealed by principal component analysis on trace element composition

UEKI, Kenta^{1*}

¹Volcanic Fluid Research Center, Tokyo Institute of Technology

Chemical composition of magma can be used to address state of the magmatic system and the processes during magma generation, ascent and eruption. Various processes from the mantle to the crust in various pressure, temperature and chemical composition modify magma composition. Consequently, bulk chemical composition of erupted magma represents a sum of these processes.

Differentiation in terms of major element composition is controlled by non-linear thermodynamic relation. Major element composition of magma is modified by temperature, pressure and H₂O content dependent saturation states of mineral phases, and partition between melt phase and mineral phases. In this sense, major element composition can be a proxy of physical state during magma generation and ascent. However, the non-linearity of major element processes and a small degree of freedom in compositional space prevent us from decomposition of processes that have derived compositional variation in terms of major element.

On the other hand, partition of trace elements between melt and mineral phase can be modeled with relatively simple equation, and can be considered as a linear process. Consequently, trace element composition of erupted magma represents a simple sum of a melting and differentiation processes. Trace element can be a tracer of the specific phase or reaction, because partition coefficients between various minerals melt show wide range of variation. Therefore, trace element can be used as a proxy of a specific chemical mass reaction process during magma generation and ascent. In addition, trace element composition shows a large degree of freedom. Therefore, it is expected that nature and the number of processes during magma generation and ascent can be decomposed by analyzing trace element composition of volcanic rock using multivariate statistics.

In this study, principal component analysis is used to analyze compositional variation of volcanic rocks in Northeastern Japan Arc.

Analysis based on a series of volcanic rocks from single volcanic activity has shown that the differentiation process and/or mantle melting process beneath each volcano (crystal fractionation and magma mixing) can be decomposed by using principal component analysis on trace element compositions. Consistent relationship between the trace element principal components, major element composition, and petrological information such as mineral composition is derived from the analysis.

In order to illustrate the differentiation process in terms of large scale spatial and compositional range, 262 samples from 17 different volcanoes in the Sengan region, northeastern Japan are analyzed with principal component analysis. Result of the analysis clearly demonstrates that differentiation processes in the arc crust, are the primary controlling factor to derive compositional variation of arc magmas. Only three principal components account for the compositional variation of 262 samples. It is estimated the three principal components represent magma mixing, relatively high pressure olivine fractionation, and relatively shallower pressure plagioclase differentiation, respectively. No strong mantle signature is identified by the analysis. This result shows intermediate-felsic magmas (SiO₂>60 wt. %) can only be derived through magma mixing, not by crystal fractionation.

Keywords: volcanic rock, arc magma, crystal fractionation, magma mixing, trace element

A preliminary estimation of water content of the mantle beneath Changbaishan Volcano, northeast China

KURITANI, Takeshi^{1*}; OKUMURA, Satoshi²; YOKOYAMA, Tetsuya³; ITO, Yoshinori²; NAKAMURA, Michihiko²; WEI, Haiquan⁴

¹Osaka City University, ²Tohoku University, ³Tokyo Institute of Technology, ⁴China Earthquake Administration

In northeast China, Cenozoic intraplate volcanic products are widely distributed. Geophysical studies have suggested that the underlying mantle transition zone is remarkably hydrous (Kelbert et al., 2009) and contains remnants of the subducted Pacific slab (Fukao et al., 1992); therefore, the Pacific slab stagnation and its relation to observed magmatism has received growing attention (e.g., Ohtani and Zhao, 2009; Richard and Iwamori, 2010). Beneath the Changbaishan volcanic field, a prominent low-velocity anomaly with a plume-like shape has been imaged in the upper mantle by P-wave tomography, which is suggestive of an upwelling of a mantle plume from the mantle transition zone (e.g., Zhao et al., 2009). In this study, to characterize the nature of the transition zone-derived mantle plume, the water content of the source mantle is estimated for basaltic products from the Changbaishan volcano.

Basaltic scoria samples were collected from a cinder cone, located about 20 km to the northeast of Tianchi volcano. One scoria sample was used for preliminary analysis of glass inclusions in some plagioclase phenocrysts. Basaltic lavas, which occur with abundant mantle xenoliths, were also collected from the outcrop near the cinder cone to know the primitive magma composition at the volcano. The MgO contents of the scoria and the lava are 5.1 wt.% and 9.1 wt.%, respectively. Major element compositions of quenched glass inclusions in the scoria sample were analyzed using EPMA, and the water contents were estimated by the difference of the analytical total of the major element analysis from 100 wt.%. Through calibration using an in-house standard glass sample of known water content, the water contents of the glass inclusions were obtained to be 0.15-3.4 wt.%. The FT-IR analysis was also performed for one glass inclusion of the estimated water content of 0.15 wt.% by EPMA, which yields the total water content of 0.2 wt.%.

Given that 3.4 wt.% represents the original water content of the melt without leakage, the H₂O/K₂O ratio of the melt of 0.90 is obtained. If we assume that the H₂O/K₂O ratio of the melt was not affected significantly by magmatic processes and the ratio is essentially constant in basaltic magmas at Changbaishan volcano, the water content of the primitive magma (2.4 wt.% in K₂O) is estimated to be 2.2 wt.%. The source mantle for the Changbaishan basalts may contain ~0.5% sediment component (Kuritani et al., 2011), and the Ce content of the source mantle is estimated to be ~1.1 ppm using the Ce content of the sediment component of 57.3 ppm (Plank and Langmuir, 1998) and that of the depleted mantle of 0.77 ppm (Salters and Stracke, 2004). If we assume that Ce and H₂O behave similarly during mantle melting (e.g., Michael, 1995), the compositions of the primitive basalt lava (Ce: 70 ppm, H₂O: 2.2 wt.%) yield the water content of the source mantle of ~350 ppm. This estimated water content is significantly higher than that of the normal depleted mantle (~120 ppm; Salters and Stracke, 2004), suggesting that the transition zone-derived mantle plume is hydrous compared with the surrounding ambient upper mantle.

In this preliminary study, we have analyzed only seven glass inclusions in a single sample, and therefore, the water content of ~350 ppm may represent the minimum estimate. It is necessary to increase the number of data by EPMA and FT-IR analyses to more reliably estimate the source water content for the Changbaishan basalts.

Keywords: mantle, water content, China

Petrological and geochemical variations within an off-axial submarine large lava flow from the Oman Ophiolite

OTSUKA, Ryo^{1*} ; KUSANO, Yuki¹ ; KANAYAMA, Kyoko¹ ; UMINO, Susumu¹

¹Department of Earth Sciences, Kanazawa University

Large submarine lava with thicknesses >100 m and volumes exceeding a few cubic kilometers are not uncommon volcanic constructs of mid-ocean ridges and around Hawaii Islands, yet details of the physical processes of eruption of these large lava flows are poorly understood. The V3 flow of the Oman ophiolite extruded at 90 Ma far off the paleospreading axis as thick lava flows with a minimum areal extent of >11 km by 1.5 km and the maximum thickness >270 m, yielding a minimum estimated volume >1.2 cubic kilometers. The V3 flow was fed by a thick feeder dike in the SW of the flow field and buried off-axial fault-bounded basins with a thick sedimentary cover in ~40 days. The upper V3 flow field consists of compound lobes that merge upstream into larger and thicker sheet-like lava, which grew endogenously as a vast sheet lobe.

Low-T hydrothermal alteration and weathering slightly modified the bulk compositions as indicated by moderate albitization of plagioclase and partial replacement of titanomagnetite and clinopyroxene by titanite and chlorite, respectively. However, strong positive correlations among incompatible HFSEs and REEs and relatively good correlations with major elements besides LILEs and Pb show that these elements were less mobile and preserve primary characteristics. FeO and TiO₂ show moderate increases with a decrease in MgO from 8 to 5 wt%, and then decreases with the decrease in MgO down to 4 wt%. 20-50 times enrichment in Th and depleted HREEs compared to primitive mantle of the V3 flow is similar to differentiated EMORBs.

Whole-rock major and trace element variations through a vertical transect at 8.7 km (T-21) from the feeder dike show fractional crystallization of clinopyroxene and plagioclase, the major phases in the groundmass of the lava, at a pressure of the paleowater depth. The stratigraphic variations show a notable enrichment in MgO and depletion in incompatible elements in the lowermost core, consistent with accumulation of olivine phenocrysts. Enrichment in incompatible elements in the uppermost core of the flow is in accordance with the model that the last solidified, residual melt resided in this horizon.

By contrast, samples collected from the basal crust every 0.5-1 km from the feeder dike, and vertical transects at 6.7 km (T-14) from the dike have whole-rock compositions spread over compositional spaces that could be explained by internal mixing of variably differentiated magmas. Interestingly, incompatible elements like Yb and Ti of the basal crust show increases downflow to ~5 km from the feeder dike and decreases further downflow. Because the basal crust is the quenched lava that came to rest first at that place, samples farther away from the feeder were extruded and emplaced later in the eruptive event. The downflow variations show extrusion of differentiated lava in the middle stage of the eruption and less differentiated lava in early and late stages. Meanwhile, the transect at T-14 is differentiated in the upper and lower crust and less differentiated in the core.

These intraflow variations in the bulk geochemistry indicate supply of less differentiated magma in an early stage of the eruption, which was progressively replaced by mixed magmas of variably differentiated and less differentiated ones toward the end of the eruption. The eruptive sequence of less differentiated to differentiated magmas with increasing FeO suggests extrusion from a density stratified magma chamber with less dense and Mg-rich magma underlain by more dense Fe-rich magma. The internal mixing among variably differentiated magmas with the progress of the eruption and the extrusion of less differentiated magma toward the end of the eruption suggest a renewal of magma toward the end of the eruption caused mixing of newly supplied less differentiated magma with the differentiated magma within the conduit and the lava tubes.

Keywords: Oman Ophiolite, obduction, V3, Large Lava Flow, chemical variation geochemistry

Factors governing fragmentation of submarine lava - mechanism of hyaloclastite formation

UMEZAWA, Yumi^{1*} ; UMINO, Susumu¹ ; KUSANO, Yuki¹ ; KANAYAMA, Kyoko¹ ; KITAMURA, Keitaro¹

¹Department of Earth Sciences, Kanazawa University

Hyaloclastite is water-lain volcanic breccia embedded in a matrix of glassy clasts by fragmentation of brittle lava under thermal stress. Fluidal basalt lava tends to form coherent flows like pillow lava and sheet flows. In contrast, viscous lava such as andesite and dacite is more likely to form hyaloclastite. This preference of hyaloclastite on lava composition indicates that mechanical response of solidified lava under stress is strongly dependent on composition. Fracturing of lava occurs when the rate of stress accumulation exceeds the rate of stress relaxation and ultimately reaches the mechanical strength of the lava. The rate of stress relaxation decreases with the increase in lava viscosity. Therefore, hyaloclastite is more common in viscous silicic lava.

However, the occurrences of pillow lava of dacite and rhyolite are known from the Ogasawara Islands, Unalaska Island, Oman Ophiolite, etc. Pillow lava is commonly associated with hyaloclastite of the same compositions. These examples demonstrate that factors other than lava composition determines fragmentation of lava. Then, the problem arises what are the governing factors that control the mechanical response of lava under stress. We will address these issues through comparative study on glass, quenched melt, of pillow lava and hyaloclastite of variable compositions spanning from basaltic andesite to rhyolite from the Eocene submarine volcanic strata in Chichijima, Ogasawara Islands.

Samples of glass from these sites were analyzed by EPMA for major elements and by SIMS for water contents. Eruption temperatures were estimated by clinopyroxene-liquid geothermometer of Putirka (2008). Crystal number densities of groundmass plagioclase and clinopyroxene were determined on COMPO images and modal abundance of constituent minerals were determined on element distribution maps of EPMA. Bulk viscosity of lava was estimated by the methods of Giordano et al. (2008) and Pinkerton and Stevenson (1992).

Dacite has phenocrysts of clinopyroxene, orthopyroxene, plagioclase and magnetite. Groundmass consists of clinopyroxene and plagioclase microlites and magnetite set in glass. In dacite glass, there is little difference in melt composition, eruption temperature, crystal number density between pillow lava and hyaloclastite. However, lower water content in hyaloclastite glass than in pillow margin glass yields higher bulk viscosity.

Andesite has phenocrysts of clinopyroxene, orthopyroxene, plagioclase and magnetite. Groundmass consists of clinopyroxene and plagioclase microlites and magnetite set in glass. Clinoenstatite xenocrysts enclosed by orthopyroxene rim are occasionally present. Hyaloclastite is higher in crystal number density and mode of groundmass plagioclase than associated pillow lava. Hyaloclastite glass is lower in Al₂O₃ than associated pillow glass, consistent with preferential crystallization of plagioclase. However, the cpx-saturated melt temperatures show little difference between pillow lava and hyaloclastite. Bulk viscosity estimated for the lava to become hyaloclastite is higher than the lava that formed pillows because of the larger crystal number density in hyaloclastite.

The above observations on dacite glass clearly indicate that water played an essential role in formation of hyaloclastite. Degassing either within the conduit or during flowage through lava tubes raised the bulk viscosity of lava and stress relaxation time, resulted in fragmentation of lava to form hyaloclastite. Although water content was not determined for andesite glass, higher crystal number density and modal amount of plagioclase in hyaloclastite with the same temperature as the coexisting pillow lava can be explained by volatile loss which raised the liquidus of plagioclase and its preferential crystallization, resulted in higher bulk viscosity and fragmentation of lava.

Keywords: hyaloclastite, the Bonin Islands Chichijima, viscosity, submarine lava

Eruption history and petrography of Akanfuji in the Me-akan volcano, eastern Hokkaido, Japan

SATO, Eiichi^{1*} ; WADA, Keiji²

¹Institute for Promotion of Higher Education, Kobe University, ²Hokkaido University of Education at Asahikawa

Me-akan volcano is located in the Akan volcanic field, eastern Hokkaido, and ~250 km inland from the Kuril trench. The volcanic activity of Me-akan volcano began at least a few tens thousand years ago, and eight volcanic bodies with different peaks have been formed.

Akanfuji (1476 m), which is the newest volcanic body in the Me-akan volcano, started its eruptions about 2.5 ka, and the volcanic activity continued for 1,500 years. The eruption products of Akanfuji are composed of scoria fall deposits and lava flows. The scoria fall deposits are distributed from northeast to south from present vent. We described the scoria fall deposits to interpret the complex depositional sequence. As a result, 17 scoria fall layers were recognized for 1,500 years.

Akanfuji had erupted basalts through its history. Two types of basalts (types I and II) are recognized on the basis of phenocrysts assemblage. Type I is orthopyroxene (opx) bearing olivine (ol)-crynopyroxene (cpx) basalt and Type II is cpx bearing ol-opx basalt. They were formed by mixing between different types of basaltic magmas on the basis of the textural and mineralogical evidences.

Keywords: Me-akan volcano, Akanfuji, Eruption history, basalt, magma mixing

Evidence of eruption episodes before AD1741 of Oshima-Oshima Volcano, Hokkaido, Japan

YOSHIMOTO, Mitsuhiro^{1*} ; NAKAMURA, Yugo¹ ; FUKUHARA, Genta² ; NISHIMURA, Yuichi¹

¹Faculty of Science, Hokkaido University, ²Faculty of Science, Hokkaido University

We newly identified two eruption episodes of Oshima-oshima volcano below eruption products of the AD 1741 eruption at an outcrop on the summit of the volcano. The upper eruption product consists of alternating volcanic lapilli fall and ash fall deposits, and the lower one consists of scoria fall deposits. Tephra from those eruptions have not found in the other area including southern Hokkaido. We also identified two thin tephra layers between three eruption products of Oshima-oshima volcano with intercalating soil layers. They are correlating with well-known wide spread tephra such as Ko-d (AD 1640) from Hokkaido-Komagatake Volcano and B-Tm (ca. AD 940) from Changbaishan Volcano, China-North Korea, based on chemistry of volcanic glass shards. Considering the thickness of soil layers, those eruption episodes would occur at around AD 1450 and BC 600. It suggests that Oshima-Oshima volcano erupted at least 4 times in last 2500 years including 2 historical eruptions in AD 1741-1742 and 1759.

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Keywords: Oshima-oshima, eruption history, tephra

Compositional variation and magmatic differentiation at the northern Kita-Hakkoda volcanic group

KOMATSU, Sho^{1*} ; OHBA, Tsukasa¹

¹Akita Univ.

Since 0.6 Ma, magmatic eruptions have occurred several times at Kita-Hakkoda volcanic group. This study focuses on the activity between 0.4 and 0.2 Ma. Magmatic differentiation process is investigated from whole-rock chemistry and mineralogy along with stratigraphy. This area consists of 12 geologic layers: Hakkoda 2nd Stage Pyroclastic Flow Deposit, Northern Kita-Hakkoda Basaltic Andesite Lavas, Lower Kansuisawa Pumice Flow Deposit, Lower Tamoyachi-dake Andesite Lavas, Upper Kansuisawa Pumice Flow deposit, the Upper Tamoyachi-dake Andesite Lavas, the Tashirotai Lacustrine Deposit, Narusawa Debris Flow Deposit, Maedake Lavas, Narusawa-daichi Andesite Lavas, Okuzuresawa Debris Flow Deposit and Okuzuresawa Pyroclastic Flow deposit in stratigraphic order. Temporal variation of chemical composition in stratigraphic order is evaluated. The activity initiated with the effusion of differentiated tholeiitic basaltic magma around 0.4 Ma. After a dormancy the activity resumed around 0.2 Ma with effusion of andesitic magma (60wt% SiO₂), followed by a fluctuating activity between tholeiitic basalt and low-silica calc-alkaline andesite magmas. Then, the magma composition jumped to high silica (60wt% SiO₂) calc-alkaline andesite. No evidence for open system process is recorded in phenocrysts in the tholeiitic rocks. Previous studies accounted for the chemical variation of tholeiitic magma by crystallization differentiation, and our new data is consistent with the model. Disequilibrium mineral assemblages in calc-alkaline rocks, e.g., coexistences of magnesian olivine and embayed quartz, and of reversely zoned pyroxenes and normally zoned pyroxenes, implies open system processes. As indicated by linear trends between tholeiitic basalt and the high-silica andesite, magma mixing is a plausible process to produce the series. Stratigraphic chemical variation might be caused by temporal variation in mixing ratios.

Keywords: Magma mixing

The volcanic history and geological structure of Sanzugawa Caldera, Yuzawa, Akita prefecture

OKI, Fumiya^{1*}; OHBA, Tsukasa¹

¹Akita Univ.

Sanzugawa caldera, located in the southern part of Akita prefecture, was formed by collapses after eruptions of voluminous ash flows about >ca. 1 Ma. Torageyama Formation, deposited during the caldera formation, thickly infills the caldera depression. The Formation is divided into two members: Torageyama tuff member and Minasegawa tuff member. Torageyama tuff member consists of welded tuff, lapilli tuff, and alternation of tuffaceous sandstone, mudstone, and conglomerate. Thickness of Torageyama tuff member is approximately 900m. Minasegawa tuff member consists of lapilli tuff, tuff and conglomerate. Thickness of Minasegawa tuff member is about 450m. In this study, on the basis of lithology, Torageyama Formation is divided into 10 layers, including pyroclastic density current deposits (PDC-1 to PDC-8), a debris flow deposit (DF-1) and a lacustrine deposit (LD-1). Stratigraphic order from the bottom is PDC-1, DF-1, LD-1 and PDC-2 to PDC-8. Approximate thicknesses of the layers are 20m, 80m, 140m, 50m, 250m, 200m, 340m, 160m, 90m and 30m, respectively. Pyroclastic density current deposits consist of massive lapilli tuff. The lapilli tuff contains pumice clasts and lithics, and minor amount of wood pieces. Bases of PDC-4 and PDC-6 consist of ground surge deposits. Low-angle cross-laminar and dunes are developed in the ground surge deposits. The ground surge deposit of PDC-6 is further underlied by a ground breccia layer. The ground breccia layer consists of matrix-supported conglomerate, containing lithics with a maximum grain-size of 2.5 m. Lapilli tuff of PDC-1, 3, 4, 8 include welded parts, developing degassing pipes and columnar joints. Welded parts often contain spherulites and exhibit eutaxitic texture. Debris flow deposit (DF-1) consists of clast-supported conglomerate with rounded clasts. The clasts are directed parallel to the bedding plane, showing coarse-tail reverse grading. Lacustrine deposit (LD-1) consists of alternation of tuffaceous sandstone, mudstone, and conglomerate. In mudstone, laminar is well developed. Laminar and bedding are well developed in tuffaceous sandstone. Conglomerate is massive. PDC-2 overlying the lacustrine deposit (LD-1) shows sedimentary structures that imply subaqueous setting. Pyroclastic density current occurred more than eight times, suggested by the number of pyroclastic density current layers. The source of PDC-4 is Takinohara vent, determined from paleocurrent estimated with dunes of a ground surge deposit. Presence of a lacustrine deposit (LD-1) in the middle of the Formation implies that caldera collapsed two times. Half-concentric distribution of strike surrounds Mt. Ishigami and their dips incline outward of the caldera. This structure implies a resurgent dome. This resurgent dome resulted in uplift of Oyasudake area where the center of the caldera. Presence of resurgent dome, thick pyroclastic density current deposits and ring fractures suggests that Sanzugawa caldera is classified as a Valles type caldera.

Keywords: Sanzugawa caldera, Torageyama Formation, Pyroclastic density current deposit, Resurgent dome

Stratigraphy and chemical compositions of eruption products in Umanose agglutinate activity, Zao volcano

KAWANO, Gen^{1*}; BAN, Masao²; OIKAWA, Teruki³

¹Graduate School of Science and Engineering, Yamagata University, ²Faculty of Science, Yamagata University, ³Geological Survey of Japan/ AIST

The newest stage of the Zao volcano, central part of NE Japan, began at about 30 ka and the activity has continued to present. The Zao newest stage eruption products are classified into Komakusadaira agglutinate, Umanose agglutinate and Goshikidake pyroclastics. In this study, we examined the stratigraphy of eruption products in the Umanose agglutinate activity (ca. 8-4 ka). Besides, we examined temporal change in chemical compositions of the products.

«Tephra-stratigraphy» We re-examined the tephra-stratigraphy and recognized nine volcanic sand layers (Z-To 5a, 5b, 5c, 5d, 5e, 5, 6, 7, 8) during the Umanose agglutinate activity. The tephra (volcanic sand) layers younger than the Z-To 5e widely distribute around the summit area, while the others are found only in the northern part. Based on ¹⁴C ages on paleosols and fossil leaf samples from the tephra-loam succession coupled with the stratigraphy, ages of Z-To 5a to 8, except for Z-To 5, are estimated to be ca. 8.9, 7.3, 6.0, 5.6, 5.3, 4.7, 3.9, 3.6 ka, respectively.

In addition, we found whitish yellow colored wide-spread tephra layer between Z-To 5e and 5d in the northern and below 5e in the southern part of the summit area. This tephra is mainly composed of pumice type volcanic glass. This layer can be correlated to To-Cu (Towada-Chuseri) tephra, based on the major element compositions of the volcanic glass and the stratigraphic horizon.

«Stratigraphy of the proximal layers» The proximal layers are well exposed in the central part of the summit area. In this part, the Umanose agglutinate covers the Komakusadaira agglutinate, which include less-vesiculated volcanic bombs with glassy luster as well as scoria. Overlying products of the Umanose agglutinate are composed of alternation of agglutinate, scoria fall deposit, and pyroclastic surge deposit. More than ten layers are recognized by intercalating loam layers.

«Temporal change in chemical compositions» The eruptive products are olivine +- pyroxene andesite (56.0-59.2% SiO₂) and belong to medium-K calc-alkaline series. All samples are plotted on same linear trends in SiO₂ variation diagrams. The silica contents increase gradually from the bottom to the middle part. Afterwards, the content drops to the lowest, and gradually increase upwards again.

Keywords: Zao volcano, Umanose agglutinate, tephra stratigraphy, evolution of magma

Eruptive History of Post-caldera Stage, East-Azuma Volcano -Correlation between ejecta intra-caldera and boring core-

OZAKI, Mamoru^{1*} ; FUJINAWA, Akihiko²

¹Ibaraki Univ., ²Ibaraki Univ.

Introduction

Azuma Volcano is one of the Quaternary stratovolcanoes located at the volcanic front of the Northeast Japan arc. The recent 7ka activities of this volcano are characterized by dominant fall out tephra (Yamamoto, 2005). Eruptive history occurred at the Jododaira explosion caldera (Fujinawa and Kamoshida, 1999) is built by comparing boring core of the Jododaira with the ejecta deposited the intra-caldera area.

Stratigraphy and lithofacies of boring core

Boring site is at about 500m NW from Azuma-Kofuji cone. This core was described most immediately after core-recovery, and stratigraphic sequence was outlined (CCPVE core analysis group, 2011). Layers of andesitic volcanic block and lapilli (11.20m-1.50m in depth) are lithologically correlated to the Azuma-Kofuji volcanic ejecta.

Andesite lava (100.55m-81.07m, sample No.19-17 near the bottom of the core) and welded tuff breccia / lapilli tuff (79.90m-14.20m, No.13-10) are to be the keys to reveal the eruption history. Andesite lava (19-17) is dark-gray in color with dominant plagioclase phenocrysts of 2~3mm in diameter. Inclusions are rarely recognizable. Welded tuff breccia/lapilli tuff (No. 13-10) are characterized by dark-gray, highly deformed and elongated blocks/lapilli at the densely welded part.

Description of outcrops

3 lava flows and 1 pyroclastic flow deposit were newly found at the outcrops of intra-caldera area.

Lava flow1 (Lf1) does not show distinct lobe topography. This is exposed only at altitudes of 430m along forest road with about 5m thick. Lf1 is massive, dark-gray in color and characterized by dominant plagioclase phenocrysts of 2~3mm in diameter. Rare cognate inclusion is also recognized.

Pyroclastic flow deposit (Pfl) intermittently cropped out around at altitudes of 470m along the route 126, showing a thickness about 2.5m. The Pfl is overlain by unconsolidated talus deposit. The stratigraphy of these deposits was not confirmed in the field observation. This Pfl includes dark-gray lithic fragments in weakly welded light-gray matrix.

Lava flow2 (Lf2) constitutes thick massive spreading widely on the floor of the Jododaira explosion caldera (Fujinawa and Kamoshida, 1999). Judged from topography, the Lf2 stratigraphically overlies the Pfl. At altitudes of 660m along forest road, the Lf2 of over 10m in thick showing an well-developed columnar joint is cropped out. The Lf2 is directly covered by Ak-Lf at this locality (Kamoshida, 1991MS). Lithology of Lf2 is massive, gray in color and pyroxene phenocrysts are discerned easily.

Lava flow3 (Lf3) is distributed in the southern part of the intra-caldera, well foamed and grey tinged with red in color. The Lf3 topographically overlies the Lf2, furthermore, and covered by Ak-Lf. The Lf3 consists of 3~5 flow units, lobes and levees at its surface.

Comparison of lithofacies

The lava samples of the core (19~17) are lithographically similar to those for the Lf1, but distinguishable to those of the Lf2 or Lf3. The core samples of the welded tuff (13~10) is slightly different from Pfl in the degree of welding, but are similar to each other in terms of including dark-gray lithic fragments in light-gray matrix.

Eruptive history based on comparison of lithofacies

The welded pyroclastic deposits in boring core are as thick as 20m, suggesting that the deposit is the deposit of an enormous pyroclastic eruption. If such eruption occurs, a sort of depression would often be remained in the supply source area. Judging from topography, the Jododaira explosion caldera is the most plausible candidate. Because the Lf1 (=core 19~17) lie beneath welded Pfl (=core 13~10), this lava is promisingly erupted during pre-caldera activities. Because the Lf2 and Lf3 are topographically come above the Lf1, it is considered that these lavas erupted in the post-caldera stage.

Keywords: Azuma Volcano, Jododaira, eruptive history, boring core, stratigraphy

Plagioclase phenocrysts and Opx-magnetite symplectite of the Sessho Lava of the Kusatsu-Shirane Volcano

OSHIO, Kazuki^{1*} ; UEKI, Kenta² ; KAWANO, Munehiro³ ; INUI, Mutsuko³ ; NOGAMI, Kenji²

¹Kokushikan University Graduate School of Engineering, ²Volcanic Fluid Research Center, Tokyo Institute of Technology, ³Kokushikan University

Chemical composition and crystal size distribution of plagioclase phenocrysts may represent the cooling rate and chemical heterogeneity of the magma chamber. Therefore, chemical and physical conditions in the magma storage before eruption can be constrained by analyzing the morphology and chemical composition of phenocrysts in lava.

For the purpose, we focused on the Sessho lava, a single lava flow erupted from Kusatsu-Shirane volcano. Kusatsu-Shirane volcano is a quaternary active volcano located in the Central Japan arc. According to Uto *et al.* (1983), the Sessho lava is estimated to have erupted from the Moto Shirane cone during an eruption about 3000 years ago. The Sessho lava shows andesitic composition (Takahashi *et al.*, 2010; Ueki and Terada, 2012). In this study, detailed descriptions in morphologies of phenocryst minerals have been carried out. We determined the modal composition of phenocrysts, and measured the aspect ratio and the crystal size distribution of plagioclase phenocryst. We also carried out the detailed description of opx-magnetite symplectite, which have been observed in several samples.

The phenocrysts assemblage of the Sessho lava is plagioclase, clinopyroxene, orthopyroxene, magnetite, and rare olivine. Groundmass shows glassy structure. Modal composition of phenocrysts shows homogeneous value in a single lava flow; 54.0 to 59.0 vol. % for groundmass, 33.4 to 38.1 vol. % for plagioclase, 2.1 to for 4.2 vol. % for magnetite, 3.0 to 6.4 vol. % for pyroxene. On the other hand, the aspect ratios of plagioclase phenocrysts show wide range of variation in a single lava flow. Fine grained plagioclase shows needle-like morphology whereas coarse grained plagioclase shows tabular morphology. Although the modal composition shows the homogeneous value, sizes of plagioclase phenocrysts show wide range of variation; samples rich in fine-grained phenocrysts and samples rich in coarse-grained phenocrysts are both present in the single lava flow.

Observations and quantitative analysis using EPMA and SEM show that the structure of plagioclase phenocrysts can be classified into following five groups; normal zoning, reverse zoning, oscillatory zoning, patchy zoning, dusty zoning. Plagioclase phenocrysts show a wide range of composition in the single lava flow. An# ranges 55-84 %. Olivine phenocryst is observed in some samples, its Mg# is -83, which is a non-equilibrium composition with its host rock.

Opx-magnetite symplectite have been observed in several samples. The symplectite show oval form. Its diameter ranges 2-4 mm. Magnetite shows lamella structure, and is concentrated at the central part of the symplectite. Orthopyroxene is 75-975 μm in diameter and distributes around the magnetite lamella. Orthopyroxene in the symplectite is characterized by its low birefringence than the typical orthopyroxene phenocrysts of the Sessho lava. This structure is estimated to be formed by the rapid oxidation of olivine, indicating that during the formation of andesite magma of Sessho lava, oxygen fugacity in the magma storage may have rapidly increased.

In conclusion, it is estimated that final temperature was homogeneous in the magma strage of the Sessho lava, because modal contents of phenocrysts in the single lava flow show homogeneous value. On the other hand, several types of the chemical composition and size of plagioclase have been observed in the lava flow, indicating rate of crystallization and cooling had variation in the magma storage of the Sessho lava. Existences of orthopyroxene-magnetite symplectite and non-equilibrium olivine indicate magma mixing and oxidization event had occurred during the formation of andesitic magma of the Kusatsu-Shirane volcano.

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Keywords: Lava flow, Crystal size distribution, Eruption, Andesite, Active volcano, Symplectite

Boring Core Observation of the Izu Oshima Sembazaki Strain Meter Well.

KAWANABE, Yoshihisa^{1*} ; ONIZAWA, Shin'ya² ; KOKUBO, Kazuya³

¹Geol. Surv. Japan, AIST, ²Meteorological Research Institute, ³Japan Meteorological Agency

We report the boring core observations of strain gauge well that Japan Meteorological Agency has been installed in the Sembasaki, Izu Oshima. The location of the well is at 34 42' 20.5168 "N, and 139 21' 40.7016"E, and well altitude is 51.2m, and drilling depth is 100m. For deeper than about 70m deep, the core was recovered.

Depth from 70m to 86m is composed of volcanic breccia with thin layers of volcanic ash. Volcanic breccia is solidified and including fragments of various basalt, scoria and altered rocks. Some basalt fragments seems to be the essential with a quench rim. From the surrounding geology, this breccia can be compared to the Senzu Formation that is the product of explosive eruption at shallow sea in the first stage of Izu Oshima volcano.

The core, depth of 86m (below sea level 34.8m) or deeper, is made of fresh aphyric basaltic lava flow. At least 2 flow units can be identified. Both lava flows contain very small amount of plagioclase and clinopyroxene phenocrysts. There is no evidence that is water-cooled to the lava flow.

We performed the whole rock chemical composition analysis for basalt fragment of breccia and lava flows. All specimen have $\text{SiO}_2 = 49.8 \sim 52.9\text{wt}\%$ and significantly lower K_2O content, about 0.2wt%, than the basalts of Izu Oshima volcano, except for one breccia fragment. The lower K_2O content than that of the rock of Izu Oshima volcano is consistent with the characteristics of the old basement volcanoes such as Fudeshima volcano.

In the sea floor of the west of the Izu Oshima, there are Semba spur accompanied by magnetic anomaly. Oshima et.al.(1987) pointed out that the Semba spur might be the older volcanic body and they named it Semba volcano. The height of the sea cliff is gradually increased from Sembazaki toward the north, and the highest around Tsuwai. The distribution of valleys around Tsuwai also shows the discordant rise in the foot of Izu Oshima volcano, and this discordant may lead to the Semba spur. The basalts from the Semba core indicate that the old basement volcano, Semba volcano, is also present in the Izu-Oshima southwest side.

Keywords: Izu Oshima, boring core, basalt

Origin and deformation of the clastic flow bands in the Takanoobane rhyolite lava

FURUKAWA, Kuniyuki^{1*} ; KANAMARU, Tatsuo² ; UNO, Koji³

¹Faculty of Business Administration, Aichi University, ²Department of Geosystem Sciences, College of Humanities and Sciences, Nihon University, ³Graduate School of Education, Okayama University

In this study, we showed that the clastic flow bands, which are developed in the Takanoobane rhyolite lava, were formed by shear fracturing of the high viscous magma within the shallow conduit. The flow bands broke up into the small particle-rich flow lines, which are ubiquitously observed in obsidian lavas.

The Takanoobane rhyolite lava (TR lava) is located at the Aso caldera in the middle of Kyushu Island in SW Japan. The lava is effused at 51±5 ka (Matsumoto et al., 1991). The thickness, estimated volume, and bulk rock chemistry of TR lava are 60-90 m, 0.14 km³ (Miyabuchi et al., 2004), and 71-72 SiO₂ wt.% (Furukawa, 2006), respectively. In this study, we examined two drill cores (AVL1 and AVL4) provided by the Aso Volcanological Laboratory. Both drill holes penetrated the proximal part of TR lava. TR lava is composed of an inner crystalline part and marginal glassy parts.

The black to dark gray colored flow bands within a few millimeters thick are concentrated around the boundary between crystalline part and basal obsidian. The bands are composed of clastic materials with a diameter below a few mm. The clastic materials are composed of glassy lithics and minerals. Some clasts are rounded and fluidal shapes and show different textural occurrences from the surrounding rhyolite. The chemical compositions of the glassy lithics and those of glassy matrix of the surrounding rhyolite are slightly different. Within the bands, the streak texture, which is defined by difference of clasts and microlite contents, is conspicuous.

The differences in texture and chemical compositions between the clasts in the bands and surrounding rhyolite indicate that the clastic bands were not formed by autobrecciation within the lava. These observations indicate that the clastic bands are likely to be formed by shear fracturing of the high viscous magma within the shallow conduit such as Tuffen et al. (2003). The fractures would become pathway of the volcanic gasses, and the clasts were transported by the gas transport. The streak texture within the bands is interpreted as sedimentary structures, which were formed by gas transportation of clasts through fracture system. The rounded and fluidal shapes of the clasts indicate that the fracturing occurred when the conduit magma was enough hot. The clastic bands consequently break up and disappear. The bands show progressive loosening along the individual streak, where will be the structural weakness. Consequently, the streak develops into the individual thin bands. The small particles, such as glass particles, microlites and lithics, are released from margin of the clastic bands to the surrounding rhyolite. Since the high viscosity of the lava inhibits their homogenization, the particles are likely to be aligned along the flow line. The clastic flow bands, originated from shear fracturing, will thoroughly break up via this process. Our results mean that the clastic flow bands developed within silicic lavas is important for understanding of the shallow conduit system of silicic magma.

Keywords: rhyolite, lava, flow band, conduit, Aso

Magma chamber processes revealed by textures in plagioclase phenocrysts through Taisho eruptions of Sakurajima volcano

YAMASHITA, Shunsuke^{1*} ; TORAMARU, Atsushi²

¹Department of Earth and Planetary Sciences, Graduate School of Sciences, ²Department of Earth and Planetary Sciences, Faculty of Sciences

Textures in volcanic products record important information about the origin of the rock. Especially, plagioclase phenocrysts have been studied in order to understand the magma chamber processes because they are commonly included in various types of volcanic rocks. Two types of plagioclase phenocrysts are found in lavas by the 1914-1915 eruption of Sakurajima volcano, Southern Kyushu, Japan: (1) honeycomb plagioclase(H-Pl) with large melt inclusions in cores; and(2) clear plagioclase(C-Pl) without any melt inclusions. In Sakurajima volcano, magma mixing has been suggested by bimodal compositions of plagioclase phenocrysts. However, relationship between textures and chemical compositions has not been reported. In addition, the crystal size distributions (CSDs) also may provide essential information for the production environment of the crystals. Therefore, in order to obtain insights into magma chamber and magma mixing processes, we conduct chemical composition and crystal size distribution (CSD) analyses.

We carried out chemical compositional analysis by FE-SEM. As a result, it is found that H-Pl phenocrysts have heterogeneous mosaic cores with An₇₅₋₉₀ and An₅₅₋₇₀ and very low An#(An₄₀₋₅₅) around melt inclusions. On the other hand, C-Pl phenocrysts are uniform in compositions while the An contents varies from grain to grain. The histogram of An contents in H-Pl cores shows narrow bimodal distributions around An₇₈ and An₈₆, whereas that of C-Pl cores shows the wide bimodal distribution around An₆₂ and An₈₆. We carried out CSD analysis. It is found that H-Pl and C-Pl phenocrysts showed different trends. CSD of C-Pl is strongly convex-downward showing crossover with two different slopes.

We revealed plagioclase are classified into three types: (1) type-H with an An-rich (An₇₄₋₈₉) and heterogeneous core containing large melt inclusions; and (2) type-C-1 with an An₆₂ and homogeneous core not containing melt inclusions; and (3) type-C-2 with an An-rich (An₈₅) and homogeneous core not containing melt inclusions. The results of CSD suggest different formation processes between H-Pl and C-Pl, and crossover in the slopes of C-Pl CSDs suggest the mixing of two magmas from which two populations of phenocrysts originate (Higgins, 1996b). In Sakurajima, magma mixing has been suggested, therefore it is important to understand the temperature of magmas. So, we estimated temperature on equilibrium constants by plagioclase- and alkali feldspar-liquid thermobarometers (Putirka, 2008). The results show the temperature on equilibrium constants of the dacitic magma was about 850 °C, and that of the basaltic magma was about 1050 °C. Since the honeycomb plagioclases are generated by the skeletal growth under high supercooling condition, the H-Pl phenocrysts is formed in the basaltic magmas during cooling at mixing events. In summary, type-H is formed by skeletal growth due to the thermal interaction during mixing events in basaltic magma, type-C-1 is formed under magma chamber with mixed homogeneous magma, type-C-2 is formed under magma chamber with the basaltic magma before mixing, respectively.

Keywords: plagioclase phenocryst, honeycomb texture, textural analysis, crystal size distribution, magma mixing, Sakurajima volcano