Japan Geoscience Union Meeting 2013
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SVC53-01 Room:201A Time:May 21 09:30-09:45

# Magma ascent process inferred from textural analysis in Tokachi-Ishizawa obsidian lava, northern Hokkaido, Japan

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Formation process of obsidian is poorly understood, while it is thought that gas loss (outgassing) plays an important role. Glass formation needs the high-effective supercooling resulted from a high ascent and decompression rates. However the high-effective supercooling increases magma viscosity, so the rapid ascending process of such a highly viscous magma is an enigma. In this study, we conducted textural and chemical analyses for Tokachi-Ishizawa (TI) obsidian lava, one of Shirataki rhyolite lava, Hokkaido, northern part of Japan, in order to elucidate the magma ascent and outgassing process, and obtain clues to solve the problem.

In Shirataki rhyolite lava area there are monogenetic volcanoes composed of 10 obsidian lava flow units, which were erupted at 2.2Ma. Rhyolite lava area with well-exposed outcrops allow us to observe the internal structure of obsidian lava flow. The stratigraphic sequence of TI lava 50 m in height is a brecciated perlite layer, obsidian layer (7m), banded obsidian layer, and rhyolite layer from the bottom. It is uncertain that brecciated perlite layer is essential. In this study, we define the obsidian and rhyolite based on the difference in appearance of specimen and rock texture, especially crystallinity. Rhyolite has perlitic cracks on glass, and contain the crystalline materials (i.e. spherulite and lithophysae). Banded obsidian layer which is located at the boundary between the obsidian and rhyolite layer, is composed of fine layer of obsidian and rhyolite. Volume fraction of the crystalline materials in rhyolite layer is up to 40 vol.%.

Obsidian in TI lava is almost aphyric, composed of glass ($>$98 % in volume), rare plagioclase phenocrysts, plagioclase microlites, magnetite microphenocrysts, oxide microlite, and rare biotite. The nanoscale crystals in obsidian glass are identified as plagioclase, based on transmission electron microscope (TEM) and field emission scanning electron microscopy (FE-SEM). This type of crystals forms microscopic layering structure in obsidian glass.

Chemical compositions of obsidian glass, plagioclase and magnetite were analyzed by electron microprobe (EPMA). Water content in obsidian glass was determined by Karl Fischer Titration (0.5-0.6 wt.%).

The maximum depth of magma chamber is estimated as $<$300MPa from the rhyolite-MELTS (Gualda et al., 2012) and petrographic characteristics. Magmatic temperature is calculated as T= 800-820 [deg C] from the plagioclase-melt geothermometer (Putirca, 2005). Magma viscosity is estimated as 4.9-8.7 [log Pa s] (Giordano et al., 2008).

We measured length, width and number of oxide microlite based on three-dimensional measuring method (Castro et al. 2003), and oxide microlite number density ($N_v$ [/m$^3$]) was obtained. From $N_v$ value of oxide microlite, $10^{13}$-$10^{14}$, and glass chemical compositions, water exsolution rate and ascent rate are inferred as $10^{-8}$-$10^{-7}$ [wt.%/s], and $10^{-5}$-$10^{-4}$ [m/s] respectively (Toramaru et al., 2008). These results means that obsidian and rhyolite experienced the same degassing rate, that is, ascent rate. This provides a constraint on the formation process of obsidian.

Keywords: obsidian, rhyolite, textural analysis

SVC53-02 Room:201A Time:May 21 09:45-10:00

# Simultaneous generation of multiple silicic magmas and their zoned magma chamber related to a caldera-forming eruption:

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It has been widely believed that a large scale, caldera-forming eruption was derived from a zoned magma chamber, which was composed of single, voluminous silicic magma associated with a small amount of mafic magma. In almost all the cases, the mafic magma injected into the silicic magma before the eruption to erupt as mixed or mingled magma with the silicic one. This is consistent with both of the temporal change of eruptive magma during the eruption and evidence of magma mingling and/or mixing. However, there also exist several eruptions in which distinct types of slicic to intermediate magmas erupted with mafic magmas. In this study, we show two examples from Hokkaido, Japan, in which ditinct silicic magmas coexisted in addition to mafic magma. During 40 ka caldera-forming eruption of Shikotsu volcano, eruptive materials can be divided into two types, aphyric (A-type) and porphyritic (P-type) ones. A type is voluminous rhyolitic magma and the mixing product of high-Si and low-Si rhyolitic magmas. These can be distinguished by Sr isotope ratios, indicating that these two magmas are no genetic relationship explained by fractional crystallization. On the other hands, the P type magma is also mixing products and several dactic and andesitic magmas. There is no mxing relationship between A and P types, indicating that the climactic caldera-forming eruption derived from simultaneous eruption of multiple magma chambers. In summary, the silicic magmas during the caldera-forming eruption of Shikotsu caldera consisted of two types of rhyolitic magmas and one or two types of dacitic magmas. In the case of 120 ka caldera forming eruption of Kuttcharo volcano (KpIV eruption), voluminous silicic magma erupted with small amount of mafic (andesite) magmas. The silicic magma is the mixing products of rhyolite and dacite magmas, which can be clearly distinguished by Sr isotopes. Thus, as in the case of Shikotsu volcano, the silicic magma of KpIV eruption consisted of multiple silicic magmas, which should be independently formed. However, these magma would be simultaneously formed. It has been widely believed that mafic magma plays as a heat source to produce silicic magma. If the silicic magmas were produced by crustal melting, partial melting of heterogeneous crustal materials might occur to produce several distinct silicic melts. It should be noted that the simultaneous generation of several types of felsic magma would be common especially in the case of large scale silicic magmatism such as caldera-forming eruptions. In such a case, mafic magma as a heat source would be enough large to melt crustal materials extensively.

Keywords: magma, silicic magma, caldera-forming eruption, crustal melting, magma genesis, zoned magma chamber

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SVC53-03 Room:201A Time:May 21 10:00-10:15

# Analysis of fractionation process of the volcanic rocks based on principal component analysis with trace element

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Detailed information of fractionation process in the crust is a fundamental issue to discuss magma generation processes in the mantle and crust, and evolution of the mantle-crust system. Major element fractionation is non-linear process which involves thermodynamic relation. On the other hand, trace element processes can be regarded as linear process, because its partition coefficient between phases considered to be unity in many cases. Hence, trace element can be a good tracer for magma mixing and involvement of a particular phase (e.g., Depaolo, 1981). To discuss fractionation process in a multi-component and multi-phase system, multivariate statistics analysis is necessary. Here we employ a principal component analysis to analyze bulk compositional trends of series of lavas from quaternary Akita-komagatake and Hachimantai volcanoes in the Northeastern Japan arc to discuss fractionation process of each volcano. Based on the principal component analysis with trace element concentrations, and petrological analysis with the major element concentrations and mineralogy, we discuss a variation of fractionation processes in the crust and also propose a possibility of employing a principal component analysis to the volcanic process.

Three principal components account for the trace element variation of the Akita-komagatake volcano. The three principal components show correlation with the major element concentration, suggesting trace and major element processes are coupled in the Akita-komagatake volcano. The three principal components can be attributed to the various degree of closed system fractionation or accumulation of olivine, pyroxene and/or plagioclase. The result is consistent with the fractionation model based on analysis with the major element composition and mineralogy or calculation using MELTS (Ghiorso and Sack, 1995).

For the Hachimantai volcano, three principal components account for the trace element variation. The first principal component represents the two component process between relatively lithophile elements rich component and incompatible elements rich component. The third principal component represents indicates involvement of mantle derived Cr and Ni rich mafic component, as have been suggested in Ohba et al. (2009). The first and the third principal components show correlation with the major element concentration. The second principal component does not show any relationship between major element composition. The third trace element component may represent selective assimilation of trace element during melt/crustal rock interaction (Watson, 1982).

Result of this study demonstrate that multivariate statistics with trace element concentrations of volcanic rock can decompose multiple fractionation process in a single volcanic suite. Our result also suggests the existence of the decouple between major and trace element processes.

Keywords: Volcanic rock, Crystal fractionation, Magma mixing, Quaternary volcano, Fractionation process

SVC53-04 Room:201A Time:May 21 11:00-11:15

# Volcanic history of the Oomurodashi, northern Izu-Bonin Arc

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Oomurodashi is a bathymetric high located ~20 km south of Izu-Oshima. Using the 200 m bathymetric contour to define its outline, the diameter of Oomurodashi is ~20 km, similar in size to the Hachijyojima Volcano. Previous dredge surveys conducted on Oomurodashi had recovered fresh pumice clasts (Hamuro et al., 1983, Bull. ERI), but since then it has been ignored, largely because it has a vast flat-topped summit at 100 - 150 meters below sea level (mbsl), and has been regarded as inactive.

However, during cruise NT07-15 of R/V Natsushima in 2007, we conducted a dive survey using the remotely-operated vehicle (ROV) Hyper-Dolphin of the small crater, Oomuro Hole, located in the center of the flat-topped summit of the Oomurodashi. The heat flow measurement conducted on the floor of Oomuro Hole recorded an extremely high value of 4,200 mW/m2. Furthermore, ROV observations revealed that the southwestern wall of Oomuro Hole consists of fresh rhyolitic lava flows.

These findings suggest that Oomurodashi is in fact an active silicic submarine volcano. To confirm this hypothesis, we conducted detailed geological and geophysical surveys of Oomurodashi in July-August 2012, again using the R/V Natsushima and ROV Hyper-Dolphin (cruise NT12-19). In addition to further ROV surveys, we carried out single-channel seismic (SCS) surveys across Oomurodashi in order to examine the shallow crustal structures beneath the current edifice.

The ROV surveys revealed numerous active hydrothermal vents on the floor of Oomuro Hole. The maximum water temperature measured at the hydrothermal vents reached 194C, almost equivalent to the boiling temperature of water at the ~200 mbsl water depths of the floor of Oomuro Hole. We also conducted comprehensive heat flow measurements across the floor of Oomuro Hole, with very high heat flows up to 29,000 mW/m2 being detected. ROV observations revealed that the area surrounding Oomuro Hole on the flat-topped summit of Oomurodashi is covered by extensive fresh rhyolitic lava and pumice clasts with minimum biogenetic or manganese cover, suggesting recent eruption(s). Furthermore, the SCS surveys revealed the presence of a buried caldera-like structure, ~8 km in diameter, beneath the flat-topped summit of Oomurodashi.

These findings strongly indicate that Oomurodashi is an active silicic submarine volcano, with recent shallow-sea eruption(s) occurring from Oomuro Hole. Since Oomurodashi is situated in a shallow-sea environment, in close proximity to the inhabited northern Izu Islands, further volcanological surveys are essential to understand the detailed volcanic history and potential hazards of this volcano.

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# Eruption history of Miyakejima Volcano, in the 9-20th century

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To make an effective forecasting of the volcanic activity in Miyakejima Volcano, it must be understand history of the post Hachodaira Caldera eruptions and the pre A.D. 2000 Caldera. Based on the caldera wall observation, tephrochronology, and radiocarbon dating, we clarify the eruption history of Miyakejima Volcano in the 9-20th century. After the 9th century the eruption number of pre-A.D.2000 Caldera is 17 times. These eruptions are flank fissure eruption in most cases. The frequency of eruption is 1-2 times in 100 years. Just before the formation of the A.D. 2000 Caldera, the 19-20$^{th}$ century, the frequency of eruption was slightly larger (3 times in 100years). But it is not a significant difference.

Keywords: historical eruption, radiocarbon dating, volcanic stratigraphy, tephrochronology, basaltic volcano, Miyakejima Volcano

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# Estimating accurate chemical composition of primitive magma by using mantle derived Opx: Targeting at the HMA in Kiyama

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High-Mg andesite (HMA) is a peculiar magma erupted in the Setouchi Volcanic Belt (SVB). On the basis of petrologic/experimental studies, Tatsumi (2006) et al. showed that HMAs in the SVB were in equilibrium with mantle peridotite and estimated the generation conditions. Petrologic study of HMA in the Kiyama district, Kagawa prefecture, shows that various crust-mantle processes were involved before its eruption. It is, therefore, necessary to accurately estimate the true composition of melt separated from the mantle by considering the processes that the HMA magmas underwent.

Chemical composition of a primitive magma is commonly estimated from an erupted differentiated magma by adding olivine in equilibrium with the melt (Tamura et al., 2000). Because the mantle olivine composition is not known, it must be assumed with or without information from phenocrysts or xenocrysts (Putrika, 2005). We discovered mantle derived Opx crystals in HMA in the SVB, the rim of which has a record of a primitive melt composition. We were successful to obtain accurate composition of the primitive magma of the HMA by using the information.

We conducted field survey in Kiyama and Kanayama (Sato, 1982), central part of Kagawa Prefecture. We also observed thin sections and analyzed whole-rock and mineral chemical composition by XRF and EPMA, respectively, and evaluated the chemical composition and generating pressure and temperature of the primary magma of the HMA.

The Sanuki Group (middle Miocene series) in Kiyama and Kanayama, referred by Sato (1982), consists of rhyolitic tuff breccias and dacitic volcanic breccias covered by sanukitoid lava flows (1, 2, 4). Lava 4 can be subdivided into 3 types according to their phenocryst combination, whole-rock composition, and amount of xenocrysts. Lava2 is abundant in olivine and Opx phenocrysts, while Lava1 and Lava4 are poor in them. Lava2 is classified into HMA and rich in Ni and Cr (8.6wt%, 180ppm, 560ppm for MgO, Ni, Cr content and 0.4 for FeO*/MgO atomic ratio), and the chemical composition is comparable to that of HMA lava flow in Goshikidai (Henmi et al., 1976).

The Lava 2 contains normally-zoned euhedral olivine phenocrysts, whose core Mg#[=100 x MgO / (MgO + FeO*)] is in equilibrium with the whole-rock composition, The olivine phenocrysts are thought to have been crystallized from the HMA melt in a closed system. The HMA also contains Opx crystals, which are either euhedral or anhedral surrounded by polycrystalline olivine rim. The Opx is reversely zoned and has Mg# much higher than that in disequilibrium with the whole-rock composition, suggesting xenocrystic origin. The very high-Mg# at the rim (up to 92.2) and $Cr_2O_3$ content (up to 1.2 wt%) suggests that they were in contact with a mantle derived melt. The Opx contains about 1.4 % CaO, from which a minimum temperature of 1100 degrees Celsius is estimated by using QUILF program (Andersen, 2008).

Because the rim of Opx probably records chemical signature of a primitive magma, from which the HMA was derived, it is possible to estimate its composition by the following procedure. First, the Mg# of olivine and melt in equilibrium with the HMA is calculated by using Fe-Mg exchange partition coefficient between olivine and melt (Beattie, 1993). The composition of primary magma is then calculated by adding fractionated olivine to the HMA until it is equilibrated with the Opx rim in terms of Mg-Fe exchange. The obtained primary magma composition in still HMA. Since olivine could have been fractionated before reaching the Mg# recorded on the Opx rim, the primitive magma could be much higher in MgO.

The composition of primitive magma of HMA in other areas might be estimated if similar mantle derived Opx is available.

Keywords: HMA, Setouchi Volcanic Belt

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SVC53-07 Room:201A Time:May 21 11:45-12:00

# Petrological comparison between products of large caldera-forming eruptions and their precursory events

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We report precursory volcanic events of large caldera-forming eruptions from Kyushu, which include (1) a series of tephra occurring 3500 years and 1000 years before the Aira pyroclastic eruption, and (2) Takayubaru lava flow extrusion just before Aso-4 pyroclastic eruption. (1) The compositions of pumice of small-scale eruptions 3500–1000 years before Aira eruption are almost identical to those of Aira pumice. (2) The compositions of lavas from Takayubaru lava lying below Aso-4 tephra without recognizable soil show a little silica-poor composition when compared to Aso-4 earliest pumice. Although both show small but definite fractionation trends, the two trends are unrelated with each other by crystal fractionation. Magma mixing, as observed in the later stage of Aso-4 eruption, was not obvious in both precursory eruptions.

Magma resorvoir model of Hildreth (1981) was the first to depict the relationship between large silicic magma reservoir in shallow crustal level and the mafic magma originated from deeper source. This model is a good springboard for discussion of precursory event of the large caldera-forming eruption, which was tested by the above observations. The case (1) corresponds to the spill out of magma from the upper part of shallow silicic crustal reservoir. The case (2) follows the estimation of spill-out event of an independent branch reservoir of large silicic magma body.

Keywords: Takayubaru Lava, Aso caldera, Aira caldera, Aso-4 pyroclastic eruption, magma supply system, Precursory eruption

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SVC53-08 Room:201A Time:May 21 12:00-12:15

# Determination of hydrogen diffusivity in Ca-rich plagioclase

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**Introduction:** Compared to studies on hydrogen diffusivity in olivine and pyroxenes, studies on hydrogen diffusivity in feldspars are very few. Plagioclase is one of the most common nominally anhydrous minerals in arc basaltic rocks, and hydrogen diffusivity in volcanic plagioclase can be applied as an useful indicator of degassing from arc basaltic magmas. Here, we performed preliminary experiments to determine hydrogen diffusivity in Ca-rich plagioclase. We also combined the obtained experimental results and analytical results of plagioclase from the 1986 summit eruption of Izu-Oshima volcano to estimate magma ascent rate.

**Experimental:** Hydrothermal annealing experiments of Ca-rich plagioclase were carried out at 300 MPa using an internally-heated pressure vessel to constrain hydrogen diffusivity in plagioclase. Experiments were performed at temperature ranging from 1000 to 1200 degree C and at $fO_2$ close to NNO buffer. Experiments were quenched after run duration of 1 to 10 hours depending on temperature. For diffusion experiments, only the relative change of hydrogen concentration is necessary and no independent calibration is required. Thus, we did not quantify hydrogen concentration in plagioclase using polarized infrared spectroscopy (Johnson and Rossman, 2003, *Am. Mineral.*) and instead we measured infrared absorption area per unit thickness using unpolarized infrared beam.

**Results:** The profile of infrared absorption area per unit thickness across the plagioclase crystal was converted to hydrogen diffusivities, which ranged from about $10^{-11}$ $m^2/s$ at 1200 degree C to about $10^{-12}$ $m^2/s$ at 1000 $m^2/s$. These results are consistent with extrapolated hydrogen extraction diffusivity determined at 1 atm under $N^2$ gas (Johnson, 2003).

**Application:** The hydrogen concentration in Ca-rich plagioclase (about $An_{90}$) from the 1986 summit eruption of Izu-Oshima volcano shows variation ranging from $<$ 50 wt. ppm $H_2O$ through 300 wt. ppm $H_2O$ as a result of polybaric degassing (Hamada et al., 2011, *EPSL*). Hydrogen concentration in each plagioclase is almost uniform across the crystal. The hydrogen diffusivity at eruptive temperature (about 1100 degree C) is about $10^{-12}$ $m^2/s$, which gives that plagioclase with high hydrogen concentration (300 wt. ppm $H_2O$) was brought from magma chamber to surface within a few hours to keep hydrogen at the core and to lose minimal amount of hydrogen at the rim. In agreement with this estimation, estimated magma ascent rate at the onset of the 1986 eruption was of the order of $10^3$ m/h based on the discharge rate of magma at that time ($>$ 2x$10^5$ $m^3/h$). As demonstrated here, hydrogen diffusivity in plagioclase can be useful as an ascent rate meter of hydrous arc basaltic magmas during explosive eruption.

Keywords: Water in nominally anhydrous minerals, plagioclase, Hydrogen diffusivity

SVC53-09 Room:201A Time:May 21 12:15-12:30

# Is magma modeled as a hard-sphere suspension or soft-sphere suspension?

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Magma is known as a complex fluid composed of three phases; silicate-melt, crystals and gases. Generally the rheology of suspension changes drastically depending on the mutual volume fraction from gaseous behavior to solid one. The rheology of magmatic system consisting of crystals and silicate melt has been modeled via hard-sphere suspensions such as a mixture of glass beads and viscous fluid. With respect to such solid-liquid system, [A. A. Arzi, 1978] introduced an important concept, Rheological Critical Melt Percentage (RCMP) 20%, which separates solid behavior and liquid behavior. RCMP is understood as a kind of jamming transition and important value since it predicts freezing rheologically above the thermodynamic freezing point. But even at larger melt percentage than RCMP, another type of significant change in the magmatic rheology has been clarified experimentally. That is the emergence of yield strength at the crystal volume fraction of around 20%. From this critical value to (100% - RCMP), magma behaves as a yield stress fluid. On the other hand, models for simple hard-sphere suspension predict this behavior at much higher volume fraction of approximately 60% e.g. [M. Otsuki et al., 2010]. Thus the range in which hard-sphere suspension behaves as a yield stress fluid is quite limited compared to laboratory-determined magmatic rheology. This is because the shape of silicate crystals in magma is generally elongated, which should be modeled as prolate or oblate ellipsoids with high aspect ratio and crystals in magma can easily form networked structures known as crystal clots, crystal cluster, synneusis, crystal chain and so on even if the particle volume fraction is small. Therefore to estimate effective volume fraction, the excluded volume should be considered [A. P. Philipse, 1996].

In this presentation we discuss whether the hard-sphere suspension is an adequate model for the magma and what are needed for proper modeling. Although individual silicate crystals are hard enough in the time scale of magma dynamics, the networked structure of crystals is quite weak and it easily breaks upon flowing stress. Yield stress emerges during breakage of the network. To look at this behavior, we consider the system should be composed of soft-sphere instead of hard-sphere, where widespread repulsive potential as well as a kind of attractive potential are needed.

We utilized an analog material, a polymer, p-NIPAM to conduct rheology characterization of suspension to see complex behaviors of magma by the deformability associated with the networked structures. In a series of our model experiments, firstly it was revealed that p-NIPAM aqueous suspension has the critical volume fraction, which is almost equivalent to that of magma. This indicates p-NIPAM aqueous suspension can be an analogue of magma to see complicated behaviors in magma caused by networked structures of crystals. At the same time it was found that this suspension has a multiplicity relationship between shear stress and shear rate and this multiplicity and the yield stress are inextricably linked together via aging effect. We consider this should be a universal characteristic for two-phase mixture system such as suspension, which has networked structures. Since magma suspension is known to have the yield stress and the networked structures of crystals empirically, this result indicates that magma can possesses the multiplicity, which can trigger self-induced oscillation phenomena.