# Two positive-feedback mechanisms controlling the bifurcation of gas-escape processes during volcanic eruptions

*Takehiro Koyaguchi[1], Yuto Inagaki[1], Tomofumi Kozono[2], Yujiro J. Suzuki[1]

1. Earthquake Research Institute, University of Tokyo, 2. Department of Geophysics, Graduate School of Science, Tohoku University

The dynamics of conduit flow is affected by density change of magma due to gas-escape and viscosity change due to crystallization. The processes of gas-escape and crystallization, therefore, lead to diverse features of volcanic eruptions such as a transition from a lava-dome forming eruption to an explosive eruption. The diverse features of eruption sequence are investigated using a model of magma plumbing system composed of a conduit and a magma chamber in elastic rocks, in which the effects of lateral and vertical gas-escape, as well as that of crystallization, are taken into consideration (Kozono and Koyaguchi, 2012). Here, using this model, we estimate the effects of gas-escape on the diverse features of eruption sequences.

Generally, the dynamics of conduit flow is controlled by the relationship between chamber pressure (P) and mass flow rate (Q) for steady conduit flow (the P-Q relationship). The diverse features of eruption sequence can be explained by the variation in the P-Q relationship. The variation in the P-Q relationship can be systematically described using the two reference relationships of extreme cases: the efficient gas escape (EGE) case and the no gas escape (NGE) case. The P-Q relationship for general cases is located between the EGE and NGE cases. In the P-Q relationship for general cases, there are two mechanisms that cause a transition from the EGE case to the NGE case and bring forward its change (the two positive-feedbacks).

The first positive feedback occurs during the waxing stage of an eruption. As the magma flow rate, Q, increases in the waxing stage, magma porosity increases with increasing Q because of less efficient gas escape, which leads to further increasing in Q because of reduction of gravitational load. This feedback mechanism causes complex dynamics; Q changes abruptly and/or cyclically even if magma supply at depth gradually increases. This abrupt increase in Q may account for the transition from a stable lava-dome eruption to an explosive eruption.

The second positive feedback occurs during the waning stage of an eruption. During the waning stage, as the chamber pressure, P, decreases, the pressure inside the conduit also becomes lower than the lithostatic pressure. The decrease in pressure inside the conduit reduces the efficiency of the lateral gas escape. This reduction of lateral gas escape increases magma porosity, which, in turn, leads to a decrease of the gravitational load and a further decrease in P. This feedback mechanism is particularly important in the sense that it controls the magnitude of decrease in chamber pressure during eruption (i.e., pressure drop), and hence, the scenario towards the end of an eruption.

Results of an extensive parametric study indicate that whether the second feedback mechanism plays a role or not is sensitive to a slight change in the permeability of the country rocks. For the condition where this feedback does not work, an eruption ends when the initial overpressure of magma chamber is relaxed. When this feedback plays a role, on the other hand, even after the initial overpressure of magma chamber is relaxed, an eruption continues until the chamber pressure becomes as low as the static pressure of gas-rich magma.

Keywords: magma plumbing system model, gas-escape process, eruption sequence, bifurcation

# Mechanisms of transitions in eruption style at the end of the 1912 eruption of Novarupta, volcano, Alaska

*Bruce F Houghton[1], Samantha J Isgett[1]

1. University of Hawaii at Manoa

The 1912 Novarupta eruption consisted of five episodes ranging from strong Plinian (mass eruption rates of 1.1 −5 x $10^8$ kg/s) to stable, steady dome effusion. Sixty hours of Plinian explosions erupted first predominantly rhyolite (Episode I) and then dacite with minor amounts of andesite (Episode II-III). Episode IV produced a dacitic block bed, interpreted as the product of complete destruction of a dacite plug/dome via Vulcanian explosions, before extrusion of a rhyolite dome in Episode V.
The transition in style and intensity from powerful explosions to dome growth is represented by three shifts in eruption style. We describe here the mechanisms of the first two shifts (lower Episode III to upper Episode III and upper Episode III to Episode IV).

The switch from sustained Plinian eruption to an unsteady subplinian phase during Episode III was brought about by progressive increase in the level of outgassing of the dacite melt remaining in the conduit. This is seen in a steady increase in the amount of dense dark grey juvenile ejecta as the outgassed melt slowed the rate of magma ascent and began to ‘choke’ the shallow conduit. The deposits are well bedded and markedly less dispersed than the Plinian falls of episodes I, II and early Episode III.

The second shift was from unsteady subplinian eruption (end to Episode III) to non-sustained transient Vulcanian explosions in Episode IV. Highly diverse juvenile blocks from Episode IV provide special insight to the state of the magma as an eruption passes from powerful sustained Plinian eruption to passive dome growth. They supply a picture of a dynamic and complex shallow conduit, now dominated by partially or completely outgassed dacitic melt that was resident at shallow levels, prior to fragmentation in repeated small Vulcanian explosions. Small total and individual explosion volume estimates, suggest that individual explosions during Episode IV disrupted the conduit to only shallow depths. Our data (1) suggest that different explosions tapped small yet diverse parts of the conduit’s architecture and (2) require a more complex model than repeated progressive evacuation in a top-down fashion of a simple horizontally stratified magma-filled conduit. The shallow conduit architecture involved both the juxtaposition of domains of contrasting texture and vesiculation state and the intimate mingling of different textures on short vertical and horizontal length scales at the contacts between these domains.

Keywords: Plinian, Vulcanian, transitions in explosive eruptions

# What can "nanolites" tell us about eruption styles?

*Mayumi Mujin[1], Michihiko Nakamura[1], Akira Miyake[2]

1. Department of Earth Science, Graduate School of Science, Tohoku University, 2. Department of Geology and Mineralogy, Graduate School of Science, Kyoto University

Crystallization of groundmass minerals record physicochemical conditions of magmatic processes upon eruption. Mujin and Nakamura (2014) reported that different assemblages of the nanolites in pyroclasts of the 2011 eruption of Shinmoedake, the Kirishima volcano, recorded the bifurcation conditions of the eruption styles. The pyroxene nanolite crystallized in both of the sub-Plinian products and the lava extrusion and Vulcanian products of the 2011 activity, whereas the plagioclase nanolite followed that of pyroxene only in the lava extrusion and Vulcanian products. They pointed out that the presence of plagioclase nanolites indicates the prolonged residence (or transit) time in the shallow conduit or crater (under large $\Delta$T) at magmatic temperature prior to the lava extrusion and the Vulcanian explosions. The lack of plagioclase nanolite gives the upper limit of the duration in which the magma ascent through the shallow conduit in the sub-Plinian eruptions, whereas the appearance of plagioclase nanolite gives the lower limit of magma residence time for Vulcanian explosions.
Following their study, we report the presence of nanometer-scale crystals down to 1 nm in the pyroclasts from the Shinmoedake 2011 eruption and their mineralogical characteristics based on field emission-scanning electron microscopy and transmission electron microscopy.
The main finding regarding nanolite crystallization is a gap (hiatus) from ˜100 to 30 nm in the size distribution of pyroxene in a dense juvenile fragment of a Vulcanian explosion. The finer-sized crystals of ˜20–30 nm were defined as "ultrananolites." In the dense fragment sample, bright spots of ˜1–2 nm in diameter were recognized in high-angle annular dark-field scanning transmission electron microscopy images. These spots are presumed to be Fe–Ti oxide, although their mineral phase was not determined due to their small size. If so, the 1–2 nm crystals are ultrananolite with a ˜9 nm gap from titanomagnetite nanolites. The pyroxene ultrananolite and Fe–Ti oxide nanolite and ultrananolite are assumed to have been formed by the additional increase in $\Delta T$ through cooling and oxidation, possibly by fragmentation followed by rewelding at the crater. Another important finding is that crystals smaller than a few tens of nanometers for pyroxene and a few hundred nanometers for plagioclase did not exist (or their number densities were too low for accurate determination). This indicates presence of practical minimum size of the crystals. These observations show that nucleation of the nanoscale crystals ceased, at least practically, in the late stage of groundmass crystallization owing to increased interfacial energy and decreased melt diffusivity in a dehydrated melt, whereas crystal growth was mostly continuous. The observation that pyroxene crystallization practically ceased before plagioclase nanolite appeared is consistent with the similarity in pyroxene characteristics such as the minimum crystal size of nanolite and the boundary size between microlite and nanolite between sub-Plinian and Vulcanian products, although plagioclase nanolites are found only in the Vulcanian products. The differences in the conditions between lava extrusions and Vulcanian explosions may be recorded in the later stage crystallization of plagioclase and Fe-Ti oxides.

# Chlorine mapping as a new tool to investigate the degassing processes of silicic magma

*Shumpei Yoshimura[1], Mitsuhiro Nakagawa[1], Akiko Matsumoto[1]

1. Department of Earth and Planetary Sciences, Hokkaido University

Vesiculation, outgassing and foam collapse are considered to be the primary control of eruption styles. However, the detailed mechanism of these processes is poorly understood. One possible way to explore this is to use the chlorine content mapping of the groundmass glass: Because of its low diffusivity, chlorine may maintain the disequilibrium distribution produced during the degassing processes. Therefore, the chlorine distribution potentially provides information about the degassing history during ascent. To examine this possibility, we carried out vesiculation and bubble resorption experiments of rhyolitic melt, and analysed the chlorine content around bubbles using an FE-EPMA. Experiments were carried out by heating hydrous rhyolitic obsidian in an open-system capsule at 1000 degC and 10-30 bar for 3-24 h. The run products showed a structure of two distinct regions: One is the bubble-rich core and the other is the bubble-free margin. The bubble-free margin is the product of bubble resorption caused by diffusive dehydration (Yoshimura and Nakamura, 2008). In the bubble-rich core, chlorine diffused towards bubbles, showing that these bubbles are absorbing chlorine during growth. The outermost bubbles are those dissolving in the undersaturated melt. These bubbles had high-Cl corona, indicating that these bubbles discharge chlorine during resorption. In the bubble-free margin, circular spots with high chlorine contents were observed. These spots represent the remnant of dissolved bubbles. These results suggest that chlorine mapping may be a powerful tool to decipher the history of degassing processes in ascending magma.

Keywords: chlorine, vesiculation, bubble resorption

# Orientation of eruption fissures controlled by shallow magma plumbing system; example of the fissure pattern in Miyakejima

*Nobuo Geshi[1], Teruki Oikawa[2]

1. Geological Survey of Japan, The National Institute of Advanced Industrial Science and Technology, 2. Geological Survey of Japan, AIST (present: Japan Meteorological Agency)

Orientation of the eruption fissures and composition of the lavas of the Miyakejima volcano indicate the competitive processes of the regional tectonic stress and the local stress generated by the activity of a magma plumbing system beneath the volcano. We investigated the distributions and magmatic compositions of the recent 23 fissures that formed within the last 2800 years, based on a field survey. Some fissures are also confirmed their eruption date by new datasets of $^{14}$C ages. The result highlights the tectonic influence of shallow magma chamber on the development of feeder dikes in a composite volcano.
As previously known, the dominant orientation of the eruption fissures in the central portion of the Miyakejima volcano was NE-SW during the last centuries, which is perpendicular to the direction of regional maximum horizontal compressive stress ( $\sigma_{Hmax}$) indicated by the regional seismicity. Our field survey reveals that the magmas that show evidence of mixing between basaltic and andesitic compositions erupted mainly from the eruption fissures with a higher offset angle from the regional $\sigma_{Hmax}$ direction.
The dike pattern perpendicular to the direction of maximum compression $\sigma_{Hmax}$ is an unusual and uncommon feature in volcanoes. The distribution and magmatic compositions of the eruption fissures in Miyakejima volcano can be explained by the tectonic influence of shallow magma chamber on the development of feeder dikes in a composite volcano. The presence of a shallow dike-shaped magma chamber controls the eccentric distribution of the eruption fissures perpendicular to the present direction of $\sigma_{Hmax}$. Injection of basaltic magma into the shallow andesitic magma chamber caused the temporal rise of internal magmatic pressure in the shallow magma chamber which elongates in NE-SW direction. Dikes extending from the andesitic magma chamber intrude along the local stress field which is generated by the internal excess pressure of the andesitic magma chamber. As the result, the eruption fissures trend parallel to the elongation direction of the shallow magma chamber. The dikes propagated from the andesitic magma chamber provide the evidences for magma mixing between the stored andesitic and injected basaltic magmas. Some basaltic dikes from the deep-seated magma chamber reach the ground surface without intersection with the andesitic magma chamber. These basaltic dikes develop parallel to the regional compressive stress in NW-SE direction. The patterns of the eruption fissures can be modified in the future as was observed in the case of the destruction of the shallow magma chamber during the 2000 AD eruption.

Keywords: eruption, eruption fissure, magma chamber, dike, Miyakejima

# Numerical investigation of temporal changes in field observations associated with volcanic hydrothermal systems during inter-eruptive stages

*Ryo Tanaka[1], Takeshi Hashimoto[1], Nobuo Matsushima[2], Tsuneo Ishido[2]

1. Hokkaido University, 2. Geological Survey of Japan

Localized temporal changes in the magnetic field and coincident ground deformation are often observed at volcanoes that have fumarolic activities (Mt. Tokachidake, Mt. Meakandake, Mt. Tarumae, Kuchinoerabujima volcano, etc.). This study focuses on two mechanisms that may bring about some changes in hydrothermal system during inter-eruptive stages: (1) permeability reduction at the shallow part of the conduit, and (2) fluctuation of hydrothermal fluid flux from a deeper part. Numerical calculation serves as a platform for systematic investigation of the surface responses to these mechanisms. We classify the pattern of temperature and pore pressure changes as well as the resulting magnetic total field, fumarolic heat discharge, and possible ground deformation that are associated with the conduit constriction and/or fluctuating flux of hydrothermal fluid by means of hydrothermal numerical simulation.

We used the numerical code "STAR" with the equation-of-state "BRNGAS" (Pritchett, 1995). It enabled us to calculate the heat and mass flow rate of $H_2O$ (vapor, liquid and two-phase) and Air in porous media over a temperature range 0–350 ºC. The calculation region was set as axisymmetric 2D to represent a simplified conical edifice. The edifice (host rock) had a uniform porosity and permeability. Temperature and pressure were maintained constant at the ground surface and on the vertical boundary of the downstream side. Thermally insulating and hydraulically impermeable conditions were imposed at the bottom boundary. Meteoric recharge was injected at the land surface at a constant rate and a constant heat flow was supplied at the base of the model. The high-permeability conduit was introduced at the axis of symmetry, hydrothermal fluid is injected at the bottom of the conduit to reproduce fumarolic heat discharge of about 100 MW, after reaching a quasi-steady condition. Thereafter, an abrupt reduction of permeability at a particular depth (PCB) in the conduit (conduit obstruction) and/or an increase in the flux of hydrothermal fluid at the bottom of conduit (increase in hydrothermal-fluid-flux) were imposed, and the system response is observed.

Conduit obstruction caused reduction in temperature and pore pressure above PCB, and increase in temperature and pore pressure below PCB. Meanwhile, increase in hydrothermal-fluid-flux induced heat accumulation and pore pressure increase around the conduit. When conduit obstruction and increase in hydrothermal-fluid-flux are introduced at the same time, whether temperature and pore pressure above PCB increase was influenced by the balance between the amount of permeability reduction of PCB and the amount of increase in flux of hydrothermal fluid. However, when the permeability of PCB after reduction was smaller than the permeability of host rock, temperature and pore pressure decrease above PCB regardless of the amount of increase in hydrothermal-fluid-flux.

In the presentation, we will discuss the change in total magnetic field, ground deformation, and fumarolic heat discharge by using these changes in temperature and pore pressure. In addition, we will try to investigate the influence of parameters such as host-rock-permeability, depth of PCB, the construction of permeability and porosity in the edifice.

Keywords: hydrothermal system, hydrothermal sealing, numerical simulation

# Conduit flow dynamics during high-flux lava effusion events at Sakurajima volcano, Japan

*Tomofumi Kozono[1]

1. Department of Geophysics, Graduate School of Science, Tohoku University

The ascent of multiphase magma in a volcanic conduit (a conduit flow) involves many complex processes such as vesiculation, gas escape, and crystallization, and it strongly controls eruption styles. By combining the modeling of conduit flow with some geological, petrological, and geophysical observations for eruptions, we can obtain detailed information on subsurface magma plumbing system. In this study, we investigated the conduit flow dynamics during lava effusion events in the historical eruptions of Sakurajima volcano, Japan by combining a 1-dimensional conduit flow model with the observed features of the lava effusion processes.

Lava effusion events during the four historical eruptions at Sakurajima volcano (1471-1476, 1779-1781, 1914, and 1946) are commonly characterized by effusions of andesitic magma from newly opened fissure vents radiating from the main summit, and the vents of the first three eruptions are symmetrically distributed with respect to the summit. Because these observations imply dike-like magma plumbing system during the lava effusion events, we added the effects of dike-like conduit geometry with an ellipsoidal cross-section to the previous conduit flow model by Kozono and Koyaguchi (2012). In the 1914 eruption, the lava effusion from the western flank showed an exponential decrease in the magma discharge rate. In the analyses of the conduit flow model, we obtain the relationship between chamber pressure (P) and magma flow rate (Q) in the steady conduit flow. When this relationship has a positive correlation, the conduit flow system becomes stable, leading to an exponential change in the magma flow rate. Therefore, we can identify magmatic and geological conditions for the exponential decrease in the magma flow rate to occur during the Sakurajima lava effusion event using the conduit flow model.

In the P-Q relationship, there are regions of positive correlation in the low-Q and high-Q ranges, whereas the negative correlation region is generated in the intermediate range by the effects of magma viscosity change due to crystallization and magma density change due to gas escape. When we define the maximum flow rate of the positive correlation region in the low-Q range (referred to as "$Q_{cr}$"), the region of $Q < Q_{cr}$ corresponds to the Taisho lava effusion phase. The results show that $Q_{cr}$ strongly depends on the parameters related to the conduit geometry such as conduit radius and the ratio of the major to minor axes of the ellipsoidal cross-section. There are two competing effects of the change in the conduit radius on $Q_{cr}$. First, as the conduit radius decreases, vertical gas escape is promoted because of the suppression of the ascent of the liquid due to the increase in wall friction force, and lateral gas escape is also promoted because of the increase in the ratio of the perimeter to the area of the conduit cross-section. These promotions of gas escapes lead to more stable effusive eruptions, which corresponds to the increase in $Q_{cr}$. Second, as the conduit radius decreases, the area of the conduit cross-section decreases, leading to the decrease in $Q_{cr}$. When the ratio of the major to minor axes changes for a given minor axis, the second effect becomes predominant. We found that a drastic increase in $Q_{cr}$ with increasing the ratio of the major to minor axes is necessary for satisfying the condition that $Q_{cr}$ becomes greater than the observed maximum flow rate during the Taisho lava eruption (about 2400 $m^3/s$). This suggests that a dike-like conduit geometry played a key role on the high-flux lava effusion processes in the Sakurajima eruptions.

Keywords: Conduit flow, Sakurajima, Lava effusion

# Lava effusion modeling by a conduit flow model coupled with the brittle-ductile transition of magma

*Satoshi Okumura[1], Tomofumi Kozono[2]

1. Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate School of Science, Tohoku University, 2. Department of Geophysics, Graduate School of Science, Tohoku University

Silicic magma forms a magmatic fault in volcanic conduits via the brittle–ductile transition of the magma. The formation of the fault changes the type of magma flow from viscous flow to friction of the magma plug (e.g., Okumura et al., 2015). Frictional stress decreases with ascent of the magma because of the reduction of normal stress on the fault, while viscous shear stress increases because of the decrease in water content and dehydration-induced crystallization. Hence, the shear stress on magma has a maximum at the bottom of the magma plug. This maximum stress may control crustal deformation during lava effusion. Here, we investigate the flow dynamics of silicic magma by coupling a one-dimensional conduit flow model (Kozono and Koyaguchi, 2012) with an experimentally calibrated brittle–ductile transition (Cordonnier et al., 2012). The results demonstrate that the length of the magma plug at which friction becomes the main flow type depends on the magma flux, because of crystallization kinetics and the ductile–brittle transition. Under high mass flow rate, the plug becomes short, because non-equilibrium crystallization inhibits an increase of magma viscosity. This results in the effusion of less viscous lava and large shear stress at the shallow part of the conduit. In contrast, the long plug that forms under low magma flux cannot maintain large shear stress due to weakness of the magmatic fault, which may cause the extrusion of a solidified lava spine. These results indicates that the transition from viscous flow to friction should be included in modeling to predict crustal deformation caused by magma ascent and understand the behavior of lava effusion.

Keywords: Lava effusion, Brittle-ductile transition, Conduit flow model

# Exsolution and dissolution of CHO fluids upon isobaric magma mixing

*Misako Nakao[1], Michihiko Nakamura[1]

1. Tohoku University

Understanding the behavior of volatile components upon magma mixing is important to comprehend the eruption dynamics, especially the triggering mechanism, as it controls the density of magmatic systems through exsolution or dissolution of fluids (bubbles). However, due to the non-ideality of the $H_2O$–$CO_2$ binary solution, the behavior of volatiles is not easy to understand. Yoshimura and Nakamura (2010) showed that $H_2O$-rich melt may vesiculate by $CO_2$-fluxing owing to a decrease in the $H_2O$ fugacity in the silicate melt. Magma vesiculation is expected to occur through a similar mechanism by mixing with $CO_2$–rich magma, although the detailed conditions have not been clarified. In this study, we calculated the changes in the solubility of the volatile components in the $H_2O$–$CO_2$ binary system upon magma mixing, and also the changes in the amount of bubbles (free-fluid phase) at 100 MPa and 100°C. In the mass balance calculation, it was assumed that magmas consist of melt and bubbles, and crystallization of basaltic melt was excluded from the preliminary calculations. The changes in the bubble content before and after the mixing were obtained for the following three initial situations. Case (1): basalt contained bubbles, but rhyolite was bubble-free, though saturated with volatile components; Case (2): rhyolite contained bubbles, but basalt was bubble-free, though saturated with volatile components; and Case (3): both basalt and rhyolite contained bubbles. The changes in solubility were investigated by employing various mixing ratios in each case.
Our findings showed that the total bubble content in the system increased under the following conditions. In Case (1), when the basaltic system is $CO_2$–rich, and the rhyolite melt is $H_2O$–rich; in Case (2), when the rhyolitic system is $CO_2$–rich and the basaltic melt is $H_2O$–rich; in Case (3), when the bubble content in the basaltic system is large, both the basaltic and rhyolitic systems are $CO_2$–rich; and when the bubble content in basalt is small, the basaltic system is $H_2O$–rich, and the rhyolitic system is $CO_2$–rich. These results suggest that the total amount of bubbles may increase during the course of mixing of magmas with different volatile compositions. Injection of $CO_2$–rich basalt into $H_2O$–rich rhyolite, which is common in arc volcanoes, may trigger volcanic eruptions.

Keywords: H2O–CO2 binary solution, triggering mechanism

# Estimation of the re-equilibrium depths of the Sakurajima vulcanian eruption magma from 2010 to 2015

*Sakauchi Nono[1], Michihiko Nakamura[1], ATSUSHI YASUDA[2], Satoshi Okumura[1], Nobuo Geshi[3]

1. Department of Earth Science, Graduate School of Science, Tohoku University, 2. Earthquake Research Institute University of Tokyo, 3. Geological Survey of Japan, The National Institute of Advanced Industrial Science and Technology

Recent studies on melt inclusions (MIs) revealed that phenocrysts are not a perfect containers of volatile components; especially water diffuses out through crystal upon decompression quickly (Mann et al.,2013). Water contents in MIs therefore record final storage pressure at which magmas were stagnant in a duration longer than that required for MIs to be reequilibrated with surrounding melts in terms of water fugacity. In the Sakurjima volcano, vulcanian explosions have occurred repeatedly since 1955. Determination of magma storage depths just prior to the explosions is useful to understand the eruption mechanisms. In this study we analyzed water contents and major element compositions of MIs in juvenile pumices from vulcanian eruptions from 2010 to 2015. The water contents of MIs were analyzed with FT-IR micro-reflectance spectroscopy (Yasuda, 2014). Most of the MIs have dacitic to rhyolitic compositions. Water contents of the MIs were mostly less than ca. 1 wt.%. Assuming water solubility of rhyolitic melt (Newman and Lowenstern, 2002) and density of the overlaying magma in the conduit to be 2400 $kg/m^3$ , this water content corresponds to below a few hundred meters.
Based on the geohygrometry of Putirka (2008), the equilibration between MIs and their host plagioclase was finally established at water contents of 1.3–2.8 wt %; this range is higher than the directly analyzed water contents of MIs, and the corresponding saturation depths were calculated to be 0.5–1.7 km. The difference from the final water reequilibration depth (< a few hundred meters) shows that the growth of plagioclase did not catch up with the magma ascent and resultant decompression and degassing prior to the explosions.
The depths of pressure sources of explosion earthquakes were estimated at 1–3 km from the crater (Iguchi, 2013), which is in between the water-reequilibration and plagioclase-reequilibration depths. Because the magma residence time at this depth is shorter than that required for the plagioclase reequilibration, degree of magma outgassing might be limited. This suggests a possibility that degassing of stagnated magma may causes pressurization to drive vulcanian explosions.

Keywords: melt inclusion, Sakurajima volcano, Vulcanian eruption

# Textural relaxation and permeability evolution of bubble-bearing magmas

*Shizuka Otsuki[1], Nobuo Geshi[1], Satoshi Okumura[2], Michihiko Nakamura[2], Osamu Sasaki[3]

1. Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, Advanced Industrial Science and Technology, 2. Division of Earth and Planetary Materials Science, Department of Earth Science, Graduate Schoolof Science, Tohoku University, 3. The Tohoku University Museum

Textural relaxation driven by interfacial tension is one of the fundamental processes in the microstructural evolution of bubble-bearing magma. A series of heating experiments of andesitic pumices by Otsuki et al. (2015) revealed that expulsion of bubbles to the outside of the system results densification and self-contraction of magma glob. In larger system, extracted vapor from the contracted melt glob may form “inter-glob pore” inside the system. Because this process may effect on the evolution of gas permeability of bubble-bearing magma, the textural relaxation process controls the outgassing within a volcanic conduit.

In this study, we examined the 3D bubble microstructure and gas permeability of the pumices after heating experiments to investigate the outgassing process from magma. The andesitic pumices of the 1914 Plinian eruption of Sakurajima were used for the starting materials. We prepared two types of the starting materials to investigate the size effect; cubes of pumice with sides 9 mm and non-shaped pumice pieces with 3–6 $cm^3$ in volume. The pumices were heated in silica glass tubes at a temperature of 1000˚C under 0.1 MPa vapor pressure for up to 32 hours (Otsuki et al., 2015), and then their gas permeability and 3D bubble microstructure were examined. The permeability of the run products was determined with the method of Takeuchi et al. (2009) and bubble microstructure was investigated using micro X-ray CT (Otsuki et al., 2015).

Gas permeability of the pumice clasts ranges between $10^{-13}$ and $10^{-11}$ $m^2$. We found that time evolution of the gas permeability depends on sample size. The permeability of the run products from cube-cut pumice with 9 mm side concentrates in relatively low value ($10^{-16}$–$10^{-15}$ $m^2$) after 8–32 hour heating, while the permeability of the run products after <2 hour run shows wider and lower ranges ($10^{-16}$–$10^{-11}$ $m^2$). The 3D analysis of the bubble microstructure shows the development of inter-glob pores formed by multiple-contraction in a run product with short heating time (~30 min). No remarkable inter-glob pore is recognized in the run products after longer run duration (8–32 h). Some run products from the large pieces of pumice kept high permeability up to $10^{-11}$ $m^2$ after 8–32 hour heating. The 3D analysis shows that some inter-glob pores still survive in these samples. Based on the 3D analysis of bubble microstructure we infer that the time scale of permeability reduction were longer due to the larger (longer) size of inter-glob pores in larger samples. Therefore, the relaxation time of the inter-glob pores seems to control the evolution of gas permeability in relaxing magma at a shallow part of a volcanic conduit.

Keywords: Textural relaxation, Gas permeability, magma

# The rapid increase of $SO_2$ emission rate observed in the Aso volcano before an explosive eruption on October 8, 2016.

*Mori Takehiko[1], Toshiya Mori[2], Fukuoka Regional Headquarters Japan Meteorological Agency

1. Meteorological Research Institute, Japan Meteorological Agency, 2. Laboratory for Earthquake Chemistry, Graduate School of Science, the University of Tokyo

Fukuoka regional headquarters, JMA is observing the $SO_2$ emission rate as one of the data for estimating the volcanic activity at Aso volcano. Although we are observing the $SO_2$ emission rate about once in one week, depending on weather conditions, the observational data cannot be obtained two weeks or more.

The observational data from August 31 to September 26 was not obtained before the explosive eruption on October 8, 2016 for weather conditions. On September 26 when the volcanic tremor was shifting on the high amplitude level, the $SO_2$ emission rate increased to 3,100 ton/day. We were worried about the rise of a volcanic activity, and shortened the measuring interval of the $SO_2$ emission rate. However, the wind velocity and direction around the Aso volcano of the beginning of October were unstable. Additionally, the detection of the high column density more than 2000ppmm made difficult the analysis of the emission rate by the present analysis method.

In this study, the observational data on October 3, 4, 6, and the 7th was re-analyzed using the absorption spectrum for every sample. The accuracy of the $SO_2$ emission rate improved by creating a calibration curve using a high column density. Although the $SO_2$ emission rate of the day before explosive eruption was calculated with 15,000 ton/day in the preliminary analysis, average rate became 16,700 ton/day (Max: 20,800ton/day, Min: 11,800ton/day) as a result of the re-analysis. Additionally, it proved that the $SO_2$ emission rate in the Aso volcano was a clear upward tendency from October. This fluctuation corresponded with the increase in the amplitude level of a volcanic tremor, and the expansion of the ground. It is assumed that a large amount of volcanic gas accumulations at the shallow region of the crater following the rapid increase in the degassing from magma had occurred in the process in which it results at the explosive eruption on October 8.

Keywords: Aso volcano, SO2 emission rate, explosive eruption

# Ground deformation preceding to the explosive eruption eruptions of Aso Volcano, Japan, October 8, 2016.

*Takahiro Ohkura[1], Shin Yoshikawa[1], Hiroyuki Inoue[1]

1. Aso Volcanological Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University

On October 8, 2016, an explosive eruption occurred at the first crater of Nakadake, Aso volcano. This eruption produced ash plumes up to a height of 11000 m asl.that drifted ESE. Prior to the eruption, remarkable ground deformation was detected by super invar-rod extensometers and water-tube tilt meters and which were installed in a 30m observation tunnel, 1km southwest from the first crater. In this presentation, we report time series of the deformation and deformation sources which could be closely related to a preparatory process of a phreatic explosion.

The first crater of Nakadake erupted at 21:52 on October 7, 2016, and was followed by an explosive eruption at 01:46 on October 8. Prior to this volcanic activity, the radial component of the extensometers at observation tunnel showed dilatation from Sep.20. This deformation accelerated on Oct. 1 and was accompanied by swarm of volcanic earthquakes and tilt change showing subsidence of the crater.
Since 1990s, observations using broadband seismometers have revealed that the source of long period tremors (LPT) or very long period (VLP) events is a crack-like conduit located at depths of 1-1.5 km beneath Nakadake, with a length of 1km and width of 2.5km. It is also revealed that at this depth a pressure source was located and caused long-period displacements a few minutes before phreatic eruption in 1993 and 1994.
Furthermore, remarkable ground deformations were detected by extensometers and tiltmeters in Sep.2013, Jan. 2014 and July 2014, which corresponded to an expansion of the crack, especially shallower than 1km below the crater.

However, it is found that observed deformation in 2016 could be attributed to the expansion of the deeper portion of the crack-like conduit. Although this expansion accelerated on Oct.1,propagation of expansion to the shallower portion was not observed although this propagation was observed in Sep. 2013 event.

Keywords: Aso Volcano, explosive eruption, crack-like conduit, ground deformation

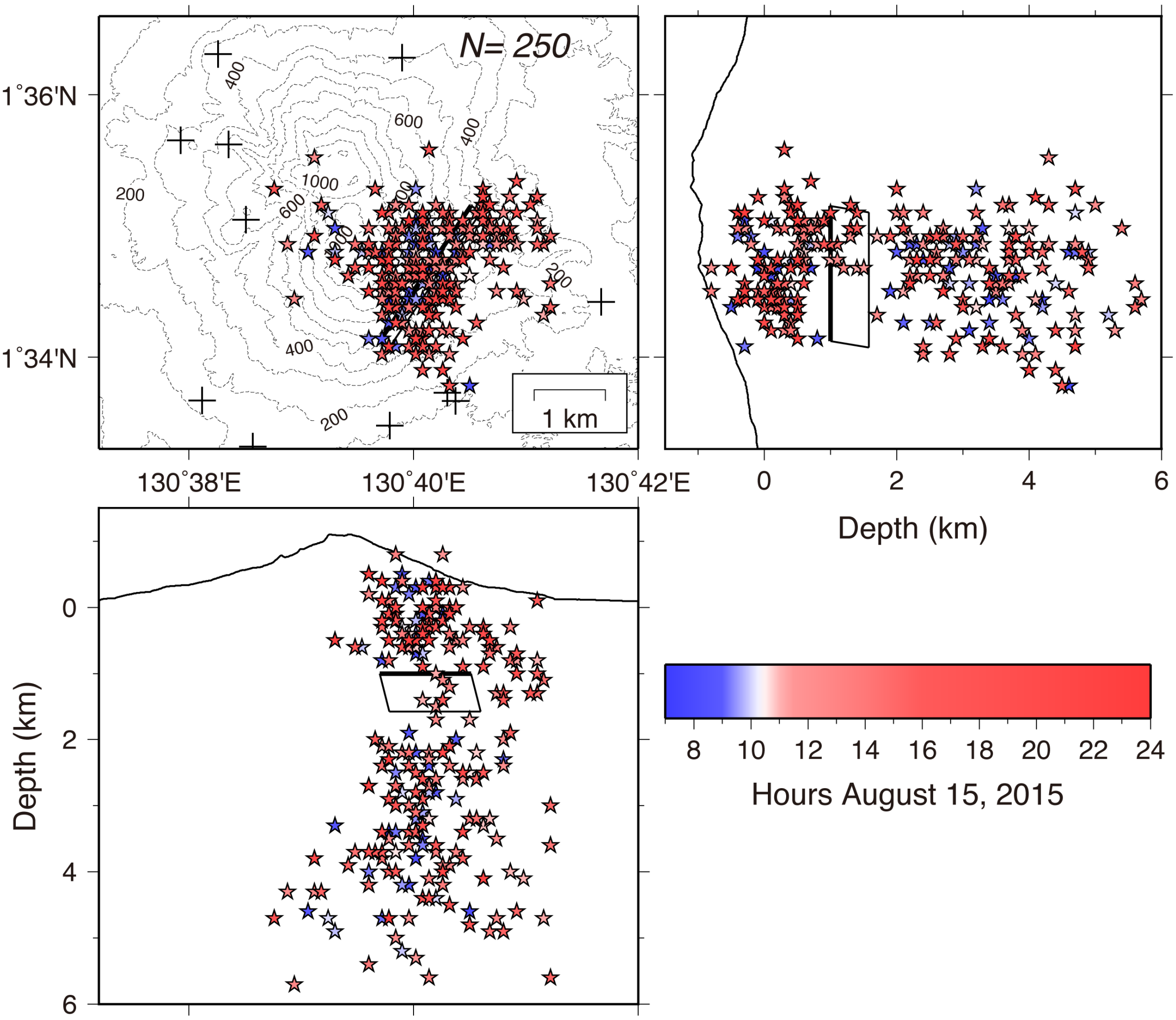
# Hypocenters of earthquakes associated with rapid magma intrusion into Sakurajima volcano in August 2015 - Estimation by the amplitude source location method -

*Haruhisa Nakamichi[1], Masato Iguchi[1], Takeshi Tameguri[1]

1. Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

We estimated 250 hypocenters of earthquakes that occurred on August 15, 2015 beneath Sakurajima Volcano, southwest Japan by using the amplitudes source location (ASL) method. A plot of residuals for a hypocenter by the ASL method shows that horizontal locations were well constrained compared with the depths. The epicenters of the earthquakes distribute in and around the dike source which is estimated by geodetic measurements (See Figure). However, the depths of the earthquakes are poorly constrained and widely distribute at -1 to 6 km below sea level. The temporal change of the hypocentral distribution is weakly seen and should be carefully examined.

Keywords: Sakurajima volcano, Hypocenter, Earthquake swarm



# Intense Swarm Activity in the Vicinity of the Sakurajima Volcano, Kyushu, Japan, in August 2015, detected by the Matched Filter Method.

*Shiro Ohmi[1], Masato Iguchi[2], Takeshi Tameguri[2], Haruhisa Nakamichi[2]

1. Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University, 2. Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

Seismic activity in the Vicinity of the Sakurajima Volcano, Kyushu, Japan was analyzed by using the Matched Filter Method (MFM). This swarm activity started on August 2015 and lasted for two days. Other authors reported that this activity was caused by a magma intrusion beneath the Sakurajima volcano by analyzing the crustal deformation data. In our analysis, we implemented MFM as a pseudo-automatic hypocenter determination system that enables to locate earthquakes one by one. Our interest is if the MFM is a useful tool for immediate grasp of an ongoing intense seismic activity.

In the MFM analysis, selection of the template earthquakes is important since the spatial distance and magnitude difference among the template earthquakes affect the detectivity of earthquakes. For this purpose, we separately implemented the conventional event detection algorithm using STA/LTA to detect possible template earthquake in order to configure a set of template earthquakes. In this stage, we set STA/LAT to a pretty large value than usual so that we can only detect those events that have rather higher S/N ratio. Then we manually inspect the hypocenter of a possible candidate of a template event to add it as a new member of the template earthquakes. When we obtained a new template, all the continuous record in the test period (48 hours starting from 00:00 August 15) are scanned by the new template to detect new earthquakes. We repeated this procedure during 4 hours from 9:00 to 13:00, August 15 to select template earthquakes. We finally selected 56 template earthquakes in this manner.

During the test period of 48 hours, about 1,900 earthquakes are detected and located with 56 templates. Automatically located hypocenters by MFM and manually inspected ones by JMA (Japan Meteorological Agency) indicates similar hypocenter distribution, and therefore the MFM possibly provide a useful information to understand the outline of the activity in the early stage. Although the manually inspected catalogue data is essential for the precise evaluation of a seismic activity, we suppose MFM is one of the powerful tools for an immediate grasp of the ongoing intense swarm activity.

Keywords: Sakurajima volcano, swarm activity, Matched Filter Method, pseudo-automatic hypocenter locating system

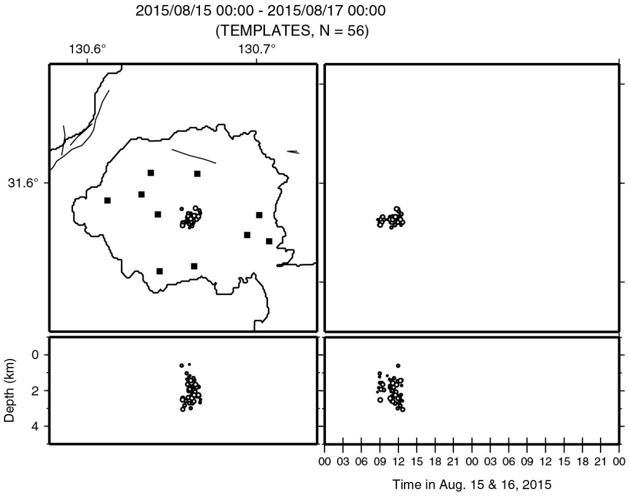

2015/08/15 00:00 - 2015/08/17 00:00
(TEMPLATES, N = 56)
130.6°
130.7°
31.6°
31.65
31.60
31.55
Depth (km)
Time in Aug. 15 & 16, 2015

Fig.1

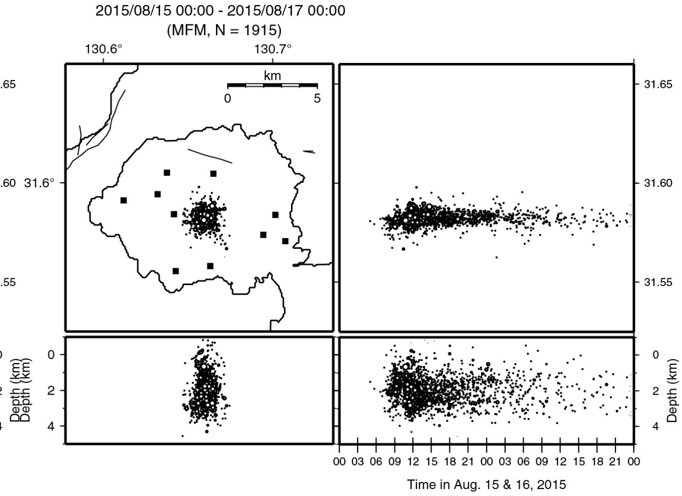

2015/08/15 00:00 - 2015/08/17 00:00
(MFM, N = 1915)
130.6°
130.7°
km
31.6°
31.65
31.60
31.55
Depth (km)
Time in Aug. 15 & 16, 2015

Fig.2

# Seismic analyses of Vulcanian eruption at Sakurajima volcano: Spectral ratio analyses of explosion and Volcano-tectonic earthquakes

*Mohammad Hasib[1], Takeshi Nishimura[1]

1. Department of Geophysics, Graduate School of Science, Tohoku University

Spectra ratios of direct and coda waves between large and small earthquake represent the differences of source time function, and have been used to evaluate the corner frequencies and magnitudes of tectonic earthquakes. We applied the spectral ratio method to explosion earthquakes observed at Sakurajima volcano, and found the spectral ratio changes with the lapse time. We inferred that the seismic waves of explosion earthquakes are generated mainly by initial rapid pressure release in the conduit but also by successive oscillations of the magma system during continuous ash emission. This observation is contrary to the results of tectonic earthquakes in many previous papers which show almost same spectral ratio between the direct and coda waves. In the present study, we further apply the spectral ratio method to the volcano tectonic earthquakes (VTs) observed at Sakurajima to examine whether or not the characteristics of explosion earthquakes represent the source process and are not affected by volcanic structures.
We analyze VTs occurring during a significant swarm in August 2015. The seismograms recorded at three JMA stations located at distances about 3 km away from the active crater (Showa crater) are used. We pick up the VT waveforms that are not disturbed by other event, and select the waveforms from large events. Then, we classify them into 2 classes according to their maximum amplitudes: the amplitudes of class I are ranging from $2 \times 10^4$ –$6 \times 10^4$ nm/s and those of class II are ranging from $8 \times 10^4$– $11 \times 10^4$ nm/s. Then, we calculate spectral amplitude ratios of large event (class II) to the small event (class I) by setting a time windows of about 5 s for the S- direct wave and coda waves at a lapse time of 5-10 s. The results show that the amplitude ratios of VTs are similar to each other between direct and coda waves. This is well consistent with the results of previous studies that analyzes tectonic earthquakes. However, VTs during the August 2015 swarm are not large enough to analyze later coda with lapse times of > 20s when the explosion earthquakes show different spectral ratios. We will analyze large tectonic earthquakes occurring around Sakurajima volcano, which generate long coda waves, to examine whether or not volcanic heterogeneous structure affect the spectral ratios.

Keywords: Spectral ratio method, VT earthquake, Explosion earthquake, Sakurajima volcano

# Triggering of volcanic eruptions: stress transfer by large earthquakes

*Takeshi Nishimura[1]

1. Department of Geophysics, Graduate School of Science, Tohoku University

It is often said that large eruptions may trigger new volcanic eruptions. Previous studies using historical data as well as recent observation results indicate that volcanic eruptions likely occur within a few days of the occurrence of large earthquakes locating close to the volcanoes (e.g., Linde and Sacks, 1998; Manga and Brodsky, 2006). However, historical data may be biased or disturbed by human activity such as world-war II. Triggering mechanism is also discussed at several volcanoes with the crustal stress changes generated by large earthquakes that may introduce magma upward migrations, but systematic research has not yet been done. The present study, therefore, analyzes recent reliable data of large earthquakes and volcanic eruptions to obtain empirical relations between the large earthquakes and volcanic eruptions. Global CMT catalog from 1976 to 2010 and Smithsonian data base of volcanic eruptions from 1966 to 2015 are used for the analyses. Large earthquakes with a magnitude of >=7.5 are selected after removal of aftershocks of other large earthquakes, and volcanic eruptions nearby the large earthquakes are searched. The results show that occurrence rate of volcanic eruptions at volcanoes located within 200 km distance from large earthquakes increases about 50 % after the occurrences of large earthquakes. The large earthquakes with M>=7.5 and locating 200 km far from the volcanoes or with M<=7.5 do not affect the occurrence rate of volcanic eruptions. The volcanic eruptions occurring within 5 years after the occurrences of large earthquakes with M>=7.5 at a distance of less than 200 km are further analyzed to examine whether the volcanic edifice are compressed or dilated by the large earthquakes. The results show that about 60 % of the volcanic eruptions occurred at volcanoes that are subject to dilatation after the large earthquakes. However, almost same percentages of the eruptions occurring before the large earthquakes are located at the dilated regions. Not only the dilatation that may lead gas bubble nucleation and growth in magma to get buoyancy force, but also the contraction that may squeeze up the magma may be the mechanisms to trigger new eruptions at volcanoes nearby large earthquakes.

Keywords: volcanic eruption, large earthquake, triggering