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

SVC50-01 Room:106 Time:May 20 11:00-11:15

An analytical formula for the longitudinal resonance frequencies of a fluid-filled crack

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The fluid-filled crack model (Chouet, 1986) has been most commonly used to interpret oscillation frequencies of volcanic earthquakes. Kumagai and Chouet (2000) systematically studied the complex frequencies of resonances of a crack filled with various kinds of fluids. Following their study, the complex frequencies of LP and VLP events at volcanoes have been linked to fluids and geometries of the cracks. So far, the crack model simulations have been performed using the finite-difference (Chouet, 1986) and boundary integral (Yamamoto and Kawakatsu, 2008) methods. These methods require computationally extensive procedures to estimate the complex frequencies of crack resonance modes. Establishing an easier way to calculate the frequencies of crack resonances would help to interpret the observed frequencies. In this study, we demonstrate that the longitudinal resonance frequencies of a fluid-filled crack can be described by an analytical formula.

We consider a 1D longitudinal oscillation of a fluid-filled crack. The fluid pressure averaged through the crack aperture, denoted as P, satisfies the following relation (Kumagai, 2009)

$(d^2/dt^2)[P(x,t)+(2b/d)u_d(x,t)]=a^2(d^2/dx^2)P(x,t)$, (1)

where a and b are the sound speed and bulk modulus of the fluid, d is the crack aperture, and u_d is the displacement on the crack surface. To derive the crack wave velocity from Eq. (1), a relation between P and u_d is required. Kumagai (2009) assumed a proportional relation between P and u_d to derive the velocity. We computed P and u_d using the FDM code of Chouet (1986), which indicated that P is proportional to u_d in time but not in space; rather the ratio u_d/P showed an ellipsoidal spatial distribution. Inserting this relation into Eq. (1) yielded a 1D variable-coefficient partial differential equation, which we semi-analytically solved to obtain a formula

$f_m=(m\text{-}1)a/[2L\{1+2e_m(b/G)(L/d)\}^{1/2}]$, (2)

where f_m is the frequency of an oscillation mode of a wavelength $2L/m$, m is an integer, G is the rigidity of the solid, L is the crack length, and e_m is a constant which depends on the oscillation mode. To check Eq. (2), we computed the oscillation frequencies for various L/d using the FDM code of Chouet (1986). The results were in good agreement with Eq. (2), suggesting that the equation adequately describes the frequency.

Eq. (2) relates the frequency f_m to the fluid properties a and b as well as the crack geometry parameters L and d. We used the equation to interpret a swarm of more than 40,000 LP events with an almost constant frequency of 0.7-0.9 Hz observed at Taal volcano, Philippines. Our waveform analyses of the events suggested a vapor-filled crack for which the fluid properties were kept constant. However, an inflow vapor volume variation causes a crack geometry change. Thus a frequency variation due to the geometry change may occur, whereas the observed frequencies were almost constant. Eq. (2) indicates that f_m is proportional to $(d/L^3)^{1/2}$ for large L/d, which suggests a constant oscillation frequency if d is proportional to L^3. We consider the crack geometry controlled by a balance between buoyancy and elastic forces. In this case, d is proportional to L^2. Assuming this relation and a vapor temperature of 600 K under a pressure of 5 MPa for the LP events at Taal, we estimated that the observed frequency of 0.7-0.9 Hz can be explained by a crack volume variation by a factor of 4. This suggests that a certain range of the inflow vapor volume variation is possible for the almost constant frequency.

The analytical formula obtained by this study may have a wide applicability to interpret oscillation frequencies of LP and VLP events at other volcanoes.

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Keywords: Fluid-filled crack model, LP events, Resonant frequency, Taal volcano

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SVC50-02 Room:106 Time:May 20 11:15-11:30

Characterization of middle-distance infrasound propagation and its utility for grasping volcanic activity

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Infrasound has become an important component of observation for volcanic activity. At present, infrasound observations for volcanoes are concentrated in two distinct scales: close to the volcano in less than 10 km, or in hundreds or thousands of kilometers away. Observations and studies of infrasound in the middle-distances are very few. We have a dense network of well-calibrated infrasound sensors around Kirishima volcano, about 40 km to NNE of Sakurajima volcano. Infrasound from Sakurajima is often observed clearly at the stations, especially at high altitudes. Strengths of the infrasound at these stations relative to a station, 3.5 km from the Showa crater of Sakurajima, show a seasonal variation and large scattering from one explosion to another. The variations are considered to be caused by changes in the atmospheric structures and possibly in the radiation patterns of infrasound. This study is motivated by this observation and aims to understand the middle-distance infrasound propagation. The middle-distance observation is particularly important for monitoring a volcano in an island, including Izu-Oshima and Stromboli. When it has large eruptions, the island may become inaccessible and stations in the island may be broken. Then, the possible nearest observation sites are in the neighboring lands, which are generally in tends of km.

We analyzed signals of Sakurajima explosions in November and December, 2012, when temporal stations were installed in various distances and directions from Sakurajima. Signals recorded at a station 43 km to SSW were quite different and much weaker than those at similar distances in NNE, the stations at Kirishima. Infrasound waveforms observed in the north and east directions were sometimes very similar regardless of distances, but sometimes clear phase splitting was recognized beyond 40 km. These features were qualitatively explained by ray-tracing calculations using atmospheric data (temperature, wind speed, and wind direction) measured at Kagoshima twice a day. Sound propagation is increased by wind toward the down-wind direction and inverse layers of effective sound speed are formed. These inverse layers were frequently formed in the direction of Kirishima but rarely to the south during the analyzed period. The inverse layers prevent upward propagation of infrasound and confine waves to increase the observed amplitudes. When the phase splitting was observed, the altitude of the main reflection was higher than usual and caused the clear splitting. When the inverse layers were not clear or lower than Kirishima peaks, the wave amplitudes were distinctly reduced behind the peaks. In this way, effects of atmospheric structure and topography, and their combination, are significant in the middle-distances. In order to obtain quantitative information of the source, we need atmospheric data with better resolutions in time and space.

Next, we focus on one explosion event. Infrasound from one event consists of an initial strong pulse and gradually decaying coda lasting 5-10 minutes, sometimes accompanying small secondary explosions. The atmospheric structure is assumed to be unchanged in this short time. In fact, the relative amplitudes of the initial pulse and the secondary ones were similar among the stations. Nevertheless, the coda amplitude relative to the initial pulse were different and decayed in various ways from one station to another, and tends to be larger beyond 15 km. Because there were also cases in which coda decayed almost in the same way at all the stations, the variation is not site effects or inevitable results of scattering. We consider it as an evidence indicating that infrasound generated by an explosion and that by a following jet have different radiation pattern and/or different source heights, that is the explosion is from the crater while the jet noise is from the turbulent ash plume (cf. Matoza et al., 2009).

Keywords: infrasound, volcano, eruption, atmospheric structure, explosion, jet

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SVC50-03 Room:106 Time:May 20 11:30-11:45

Glow luminance change at 1 second before an explosion of Sakurajima volcano

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We will present some movies that show the volcanic glow and its luminance change before an explosion of Sakurajima volcano, Japan. Since December 2011, we observed 11 events that show the abrupt glow luminance change at 1 second before an explosion. In this presentation, we will investigate the mechanism of the glow luminance change by comparing movies with infrasound, strain, and seismic data.

SVC50-04 Room:106 Time:May 20 11:45-12:00

Magma reservoir?vent system within Miyake-jima volcano revealed by GPS observations

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Analysis of GPS data during the degassing stage of volcanic activity at Miyake-jima volcano, Japan, in 2000 indicates a source of crustal deformation on the south side of the summit crater wall at a depth of 5.2 km. The rate of volume fluctuation was ?3.8 x 106 m3/month from September 2000 to January 2001 and ?0.8 x 105 m3/month from February to June 2001. As the volume is equivalent to the volume occupied by the volatile components dissolved in the magma, it is proposed that contraction of the magma reservoir reflects degassing of its volatile components. The observations indicate that the magma reservoir is connected to the summit crater by a magma-filled vent. Convection within the vent carries volatile-rich magma upward to the crater, where volcanic gas is released by degassing. The depleted magma is then carried into the magma reservoir, which contracts due to the loss of volume originally occupied by the volcanic gas.

Keywords: Valocanic eruption, Volcanic gas, magma convection in conduint

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SVC50-05 Room:106 Time:May 20 12:00-12:15

3-D numerical simulations of eruption clouds: Efficiency of turbulent mixing caused by environmental wind

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During an explosive volcanic eruption, volcanic gas and ash are ejected from the volcanic vent. Depending on terminal velocity, the particles (i.e., volcanic ash) are carried up within a convective plume, are advected by the surrounding wind field, and sediment on the ground. The fine particles are expected to have atmospheric residence, whereas the coarser particles form ash-fall deposit. Recently, particle-tracking models such as PUFF and advection-diffusion models such as TEPHRA2 and FALL3D tried to forecast both particle concentration in the atmosphere and particle loading at ground level. In these models, the source conditions (the plume height, and mass release level) should be given on the basis of a simplified model of bent-over plume (e.g., Bursik, GRL 2001) which contains an empirical constant (entrainment coefficient related to the wind-caused entrainment, b). In order to determine the value of the parameter (i.e., b) and the other source conditions for tephra dispersion, we are developing a 3-D numerical model which reproduces the dynamics of convective plume, the ash transport, and fallout deposits.

The model is designed to simulate the injection of a mixture of solid pyroclasts and volcanic gas from a circular vent above a flat surface in a stratified atmosphere, using a combination of a pseudo-gas model for fluid motion and a Lagrangian model for particle motion. During fluid dynamics calculations, we ignore the separation of solid pyroclasts from the eruption cloud, treating an eruption cloud as a single gas with a density calculated using a mixing ratio between ejected material and entrained air (Suzuki et al., JGR 2005). In order to calculate the location and movement of ash particles, we employ Lagrangian marker particles of various sizes and densities. The marker particles are ejected from the vent with the same velocity of the eruption cloud every 10 sec. The particles are accelerated or decelerated by the drag force on the spheres and fall to the ground with their terminal velocities.

We carried out a series of simulations of a small-scale eruption in various crosswind fields with the magma discharge rate of 2.5×10^6 kg/s, the initial temperature of 1000 K, and volatile content of 2.84 wt. %. The simulation results show that as the wind speed increases the mass of the entrained air increases and the plume height decreases. Through comparisons between the present results and the 1-D model predictions, we found that the preferable value of b (0.2-0.3) is substantially smaller than those suggested in previous works (0.3-1.0). The simulation results also indicate that (1) the main mass release level of particles is lower than the total height of plume, and that (2) it depends on the particle size. We confirmed that the present model correctly reproduces the plume height and ash fall area during the 2011 Shinmoe-dake eruptions (Suzuki and Koyaguchi, AGU 2012 Fall Meeting).

Keywords: eruption cloud, tephra dispersal, turbulent mixing, volcanic disaster prevention

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SVC50-06 Room:106 Time:May 20 12:15-12:30

Relationship between Stratigraphic Variations of Grain Size Distribution in Fall Deposits and Initial Size Distribution

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In general, a stratigraphic variation in characteristics of grain size distributions of pyroclastic deposits may reflect the temporal behavior of the eruption intensity. However, quantitative methodology to link the stratigraphic variation and the temporal behavior of eruption intensity has not been established because of the complex coupling of several processes: eruption column dynamics, fallout process, sedimentation, erosion etc. In this study, we investigate only the effect of sorting process during settling on the stratigraphic variation of pyroclastic deposits.

In order to relate the variation of grain size distribution as a function of stratigraphic height to the sorting process during settling, we developed a theoretical argument from the view point of Lagrangian manner. If we assume that the terminal velocity of a particle is only a function of grain size and coagulation effect is negligible, an increasing rate of deposit layer equals the volume flux which is calculated from sedimentation rate, leading to an integrodifferential equation including the initial size distribution and the height in the deposit layer. If the initial distribution is given, the solution of the integrodifferential equation gives grain size distribution of deposits as function of height.

We carried out some simulations with our numerical model. In the simplest case that grains start to fall from a constant fallout height on an instantaneous time with no duration, grain size uniquely increases depending on stratigraphic height in deposits with no variance. Extending this simplest case to more realistic case with finite duration of falling, results show that the variation of grain size distribution takes non-zero value of variance. In these cases that fallout height and initial grain size distribution are constant with time, it is shown with the mathematical formalism that the values of Md vary from coarse to fine from the bottom to the top, although this grading behavior has been qualitatively predicted.

From comparison with the stratigraphic variation data of pyroclastic deposits of the 2011 Shinmoedake subplinian eruptions, which have the single coarsest peak of the Md value in a single eruption, we concluded that it is impossible to reconstruct this observed variations in the case of constant fallout height and initial size distribution with time. In order to successfully explain the observed grain size data, we need to give the temporal variation of fallout height or initial size distribution in future.

Keywords: grain size distribution, stratigraphic variation, pyroclastic deposit, eruption intensity

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SVC50-07 Room:106 Time:May 20 12:30-12:45

Friction properties controlling deposit shape of pyroclastic flows: insights from eruptions of Soufriere Hills volcano

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Dense pyroclastic flows generated by the collapsing of lava domes are often encountered in effusive volcanic eruptions. Capturing the major characteristics of such flows is important to assess volcanic activities and hazards, but is a significant challenge because the mechanics of the grains and their interactions are incompletely understood. One approach has been to exploit the thinness of the flows relative to their length by employing a depth-averaged description in which the flow is assumed to have a constant bulk density. A key issue is the granular friction law that is introduced into depth-averaged models. Recent laboratory studies on dense granular flows suggest that rheology can be described by a friction coefficient. Variation of this coefficient with shear rate and pressure is captured through a dimensionless inertial number. Under the shallow water assumption how well this friction model works remains unclear when applied to pyroclastic flows.

Recent dome collapse events in Soufriere Hills volcano, Montserrat, provide good examples to study the dynamics of dense pyroclastic flows and to examine granular flow models, because of abundant geological and geophysical data. In this study, the July 2003 and May 2006 dome collapse events and resultant pyroclastic flow deposits are investigated. The most intense phase of the 2003 event produced the deposit 170 M m^3 in 2.6 hours, and the shape of proximal submarine deposit offshore Montserrat is characterized by semicylindrical, steep-sided lobes. The 2006 event produced 97.8 M m^3 in 35 min and the deposit is characterized by a more elongated shape in flow direction than the 2003 deposit and by channel and levee-like facies (Trofimovs et al., 2012, BV). Geophysical observation such as seismic and strain records also constrain the variation of discharge rates of pyroclastic flows during the events.

To investigate the factors controlling the shape of pyroclastic flow deposit, we used a 2D shallow water model with two types of Coulomb-type friction models. One had a constant friction coefficient, and another had a friction coefficient that depends upon the dimensionless inertial number of the motion. The models are applied to a simple system or the terrain of Soufriere Hills volcano. When the latter friction model was examined, the variation of deposit shape such as channel and levee-like facies was reproduced, depending on initial mass, discharge rate or slope angle. Also our numerical results suggest that the inertial number dependent friction model works better after the flow passing a slope break point where slope angle is equal to the friction angle at zero shear rate. Coupling effects of discharge rates, slope and granular friction properties may explain the different shapes of the pyroclatic flow deposits produced by dome collapse events in Soufriere Hills volcano.

Keywords: pyroclastic flows, deposit shape, friction, lava dome collapse, Soufriere Hills Volcano

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SVC50-08 Room:106 Time:May 20 14:15-14:30

Analysis of eruption sequences based on a model of magma plumbing system: Effects of variable magma temperatures

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How the magnitudes and time intervals of volcanic eruptions are determined is one of the basic problems for better understanding of eruption mechanism as well as eruption prediction. We intend to analyze this problem based on a simple model of magma plumbing system. Our main interest is to find physical factors that control eruption sequences. The analysis is based on a model of magma effusion that formulates the opening and closure of an exit conduit through viscous deformation of the ambient country rock responding to magma pressure (Ida, GRL, 23, 1457-1460, 1996). Using this mechanical model, we showed last year how much varieties of eruption sequences are generated under periodic supplies of magma flux, but calculated eruption sequences were not variable enough to compare with natural eruptions. So we here study the problem taking the effect of changing magma temperature into account.

The model used in this analysis consists of a magma chamber with variable pressure and an attached exit conduit with variable radius. Magma pressure in the chamber elastically responds to the supply and emission of magma compared with its capacity, and the exit conduit opens and closes through viscous deformation of the ambient country rock following pressure change. The magma flux that flows out in the exit conduit is determined as a continuous function of time by solving a set of simple ordinary differential equations but the flux is actually concentrated into some points of short time intervals so as to give effectively discrete episodic eruptions. We further consider the thermal effect in which heat is lost from the magma chamber by thermal conduction. The magma temperature is determined by the balance between conductive heat loss and mixing of supplied hot magma and influences the magma outflow process through the temperature dependent magma viscosity.

For a constant magma supply rate the calculated magma temperature converges on a certain value that balances cooling effect with magma supply so that the thermal process little affects manners of magma effusion. When the supply changes periodically the magma temperature follows the supply with a delay associated with thermal conduction and influences the effusion process. Time intervals between eruptions as well as erupted masses of individual eruptions change in various ways, fluctuating sometimes periodically and sometimes with their gross long-term variations. Magma temperature changes more moderately over the eruption sequences. Features of eruption sequences sensitively reflect the period of magma supply and the efficiency of thermal conduction.

The calculation result in smaller time scales shows detailed natures of magma supply during individual eruptions. The supply history in an eruption gives an almost symmetric curve before and after the peak. Namely, supplied magma flux increases to the peak in a certain time and decreases to the end in an almost same time. Within the same eruption sequences the duration of an eruption tends to be shorter as the erupted mass is greater. Magma temperature increases a little during an eruption but its change is small.

Because real eruptions occur in a quite variable way it is not easy to find common natures of eruptions empirically. In most volcanoes available data of eruption histories are too poor to draw some definite conclusions on statistical natures of eruptions. Our analysis may help to reduce such difficulties.

Keywords: volcanic eruption, eruption sequences, magma temperature, magma chamber, magma plumbing system, computer simulation

SVC50-09 Room:106 Time:May 20 14:30-14:45

Modeling of gas bubbles rise in low viscous magma and volcanic deformation

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Eruptions characterized by low viscous magma, such as Strombolian type eruptions, are considered to be generated by a sudden release of a large gas slug. Because ascending slug acts a deflation source, volcanic deformation due to gas slug rise shows deflation at the stations far from the vent (Kawaguchi et al., 2011, JPGU). However, tilt data observed at Stromboli volcano show inflations prior to each eruption at a station away about 1 km from the vent (Genco and Ripepe, 2010). This observation suggests that the slug flow model may not explain these observed data. In this study, we model the gas bubbles rise process in melt and examine the spatio-temporal changes of volcanic deformation due to gas bubbles rise.

We assume that gas bubbles which have a same radius concentrate at a certain depth in cylindrical conduit. According to Stokes' law, individual gas bubbles rise without interaction with surrounding gas bubbles. As gas bubbles rise, the pressure of surrounding melt decreases and gas bubbles expand. Magma head depth ascends by gas bubbles expansion. Using the mass conservation law of liquid melt, temporal changes of the depth and radius of gas bubbles and magma head depth are calculated. Magma pressure at shallow part of the conduit increases with the rise of magma head depth. The void ratio of magma where the gas bubbles exist increases with gas bubbles expansion. As a result, magma pressure at deeper part of the conduit slightly deceases. We examine the spatio-temporal changes of volcanic deformation due to the gas bubbles rise. We assume that many gas bubbles concentrate at the bottom of the conduit at the beginning, and an eruption occurs when the gas bubbles reach the magma. Because the gas bubble velocity is proportional to the square of gas bubble radius, the gas bubbles rise in melt at an accelerated rate. As a result, the magma head depth ascends at an accelerated rate in the conduit. We calculate volcanic deformation due to the gas bubbles rise, assuming an open conduit and elastic half-space. At a station at a same distance of the initial gas bubbles depth from the vent, displacement and tilt increase at an accelerated rate with magma head ascent. The amplitudes of deformation increase with increasing the initial gas bubbles radius or the number of gas bubbles. Because pressure decrease at deeper part of the conduit become smaller than that of slug flow model, volcanic deflation is not likely to appear at a station far from the vent. The tilt changes calculated by gas bubbles rise model fairly well explain with the observed tilt change prior to the eruption at Stromboli volcano which are reported in Genco and Ripepe, (2010). As a result, gas bubble rise model can explain the volcanic inflation at a station far from the vent.

Keywords: open conduit, gas bubble rise, volcanic deformation, Strombolian eruption

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SVC50-10 Room:106 Time:May 20 14:45-15:03

Perspective on textural study of volcanic products

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The textural and compositional characteristics of erupted products record the history of dynamics which magmas experienced in the conduit invisible. During this decade, the methodologies have been increasingly developed to quantitatively decode the records from the textural and compositional data. For instance, estimations of saturation depth, decompression rate during magma ascent and retention time at depth have been made possible on the basis of microlite compositions, bubble and microlite size distributions. As the results, together with data by the geophysical and geochemical observations, we have been able to draw a realistic view of magma migration from the source region to the surface. This development is a convincing consequence from the simultaneous progresses in three different areas; experimental studies reproducing textures and chemical compositions of erupted products, technology of observations and measurements, and theoretical studies to physico-chemically interpret the textural and compositional data. However, in spite of such progresses, we have not yet succeeded to exactly predict the motion of magma and to quantitatively reconstruct the temporal developments of past eruptions combining the geological information. Much less, we have a long and winding road to discover the rules related to eruption phenomena, such as key observational signals to indicate the mass and style of a future eruption. When we look at the circumstances in material sciences of volcanic products from the view point of this difficulty, we inevitably recognize the defects in current understandings on several fundamental problems, such as the physical origin of the variety in bubble and microlite size distributions and the chemical compositions of minerals crystallizing under disequilibrium conditions. In this talk, I present the current circumstances of CSD (Crystal Size Distribution) studies and propose a new methodology to inversely estimate changes of pressure and temperature as functions of time from CSD with applications to erupted products.

Keywords: textural study, volcanic products, CSD

SVC50-11 Room:106 Time:May 20 15:03-15:18

Magma mixing/mingling and viscous fingering: Analog model experiment and geometry of interfaces

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Magma mixing/mingling is common in the dynamics of volcanic eruptions and igneous activities, and its processes have been investigated by several experimental and theoretical studies (Eichelberger, 1980; Koyaguchi, 1985; Wada,1995). Especially, the morphology of interfaces between the magma have different viscosity shows the various complex patterns due to the difference in physical and chemical condition under the mixing/mingling process (De Rosa et. al., 2002; Perugini et. al., 2005; Sato and Sato, 2009). Since the quantity that we can observe easily now is the geometrical patterns of the interfaces, it is important to express this physical phenomenon in terms of the geometrical quantities of the interfaces. In this work, we call it as the geometry of interfaces.

The geometry of interfaces enables us to extract the useful information of the mixing/mingling process from the morphological analysis of the interfaces of rocks in nature (Perugini and Poli, 2005; Sato and Yamasaki, 2012). However,few attempts have been made to consider how the dynamic quantities such as the growth rate of the interfaces affect the geometry of the interfaces in the mixing/mingling process. The purpose of this work is to clarify this point based on the analog model experiment and the differential geometry.

In this work, to simulate the replenishment of felsic magma chambers/pockets by continuous inputs of mafic magmas, we perform the analog model experiment in which we inject air into glycerin using the Hele-Shaw cell. In this case, the mixing/mingling process can be described by the DLA model (e.g., Nittmann et al., 1985), and the interfaces show the viscous fingering pattern due to the instability of the interfaces that also occur in the natural cases (e.g., Perugini and Poli, 2005). The following results were obtained.

(1) We estimate the three fractal dimensions: the interfaces Di, the area of the higher viscosity fluids Dh and that of the lower viscosity fluids Dl. We find that the sum of Dh and Di is the conserved quantity, and the Di is proportional to Dl. This implies that the fractal dimension of the interfaces (easily observed quantities) enables us to estimate the fractal dimension of the area of the felsic or mafic magma (hardly observed quantities).

(2) We find that the radius of curvature of the viscous fingerling depends on the growth rate of the interfaces. This is agreed with the solutions of the development equation of the curvature in the differential geometry (e.g., Nakamura and Wadati, 1993). This implies that we can estimate the growth rate of the interfaces by the radius of curvature of the mafic magmas.

Keywords: magma mixing, viscous fingering, fractal dimension, Hele-Shaw cell, curvature, DLA

SVC50-12 Room:106 Time:May 20 15:18-15:36

Basaltic magmas at high pressures and the origin of the lithosphere-asthenosphere boundary

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Basaltic lavas rise buoyantly from the Earth's mantle to form the oceanic crust, and are an important source of terrestrial volcanism. The density and viscosity of basaltic magmas moderates igneous processes ranging from volcanic activity to fractionation, and is intimately linked to its atomic structure. Here we show that basaltic magmas undergo rapid densification with increasing pressure and exhibit a viscosity minimum near 4 GPa, correlated with an increase in coordination number for Si^{4+} and Al^{3+} cations. Magma mobility- the ratio of the melt-solid density contrast to the magma viscosity- exhibits a peak at 120-150 km depth that is up to an order of magnitude greater than values in the shallower lithosphere and deeper mantle. Thus the driving force for melt separation in Earth's asthenosphere diminishes as melts ascend, which could lead to excessive melt accumulation at depths of 80-100 km, providing a simple explanation for the occurrence of a seismically-observed Gutenberg discontinuity.

Keywords: basalt, magma, high pressure, density, viscosity, structure

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Effects of vertical diffusivity of particles on distribution of deposits calculated by the tephra-tracking model PUFF

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Understanding the process of tephra dispersion is scientifically important in order to estimate eruption conditions from tephra fallout deposits and also socially and economically required to prepare for risks of tephra-fall, such as air traffic disruption and damages to agriculture, infrastructures and buildings. For this reason, advection-diffusion models for tephra transportation have been developed with simplified assumptions (e.g., TEPHRA2). The final goal of this study is development of a new advection-diffusion model which correctly reproduces the physical process of tephra dispersion in the atmosphere.

In TEPHRA2 model, vertical diffusivity of particles is assumed to be negligible. Under this assumption, if the tephra particles of a single grain size are supplied from a point source in the atmosphere, the distribution of the diffused particles is described by a bivariate Gaussian distribution. When the particles with various sizes are released from different heights, the distribution of the entire tephra deposit can be expressed by a simple superposition of bivariate Gaussian distributions. This assumption makes analyses of geological data easier; however, its limitation should be carefully evaluated because the effect of vertical diffusivity on distribution of tephra deposit is not clear. In this study, we systematically investigated the effect using a particle-tracking model (PUFF).

In PUFF model, Lagrangian particles are advected with the local wind velocity and fall with their terminal velocities. The horizontal and vertical diffusions of particles due to atmospheric turbulence are simulated by random walk formulation. In our calculation, single-sized tephra particles are released from a point source above a vent and they are advected and diffused under a uniform wind condition.

In each run, the released particles diffuse and form a "particle cloud"; the size of cloud increases with time. Because horizontal diffusivity is set to be much larger than vertical diffusivity, the particle cloud has an oblate spheroid shape. The particle cloud moves horizontally with wind speed and fall to the surface at terminal velocity of particles. There is a time lag between depositions of particles at the bottom and those at the top of the particle cloud extending vertically due to the presence of vertical diffusion. Because of the presence of horizontal wind, the particle cloud keeps its horizontal movement until the settlement of its top after the landing of its bottom. As the result, the tephra particles are finally deposited in an area elongated and slightly widening toward downwind; the distribution of particles on the ground deviates from the bivariate Gaussian distribution. To compare the particle distribution with a bivariate Gaussian distribution, variance, skewness and kurtosis of the particle distribution in parallel and cross wind direction are calculated. The particle distribution has larger variance, skewness and kurtosis in parallel wind direction, whereas larger kurtosis in cross wind direction. These deviations from the bivariate Gaussian distribution are more remarkable for finer particles, lower point sources and faster wind speed condition.

The above results suggest that the vertical diffusivity plays an important role in the distribution of tephra fall deposits. The limitations (source height, grain size, wind speed) of the bivariate Gaussian distribution assumption can be determined by the quantitative comparison with tephra deposits calculated with PUFF model.

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Immediate estimating plume height of volcanic eruption by not using visual observation

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In order to reduce volcanic disaster, it is important to detect the eruption and estimate the plume height of volcanic eruption. Taller plume obstructs aircraft flight paths, and lapilli lifted upward in the growing plume fell to a long way by upper wind effect. In the case of the Shiomoedake eruption, February 2, 2013, the lapilli reached up to 16 km from the vent. This time, the plume was not able to be seen by low-level clouds. So it is necessary to estimate plume height by not using visual observation.

Sparks et al. (1997) showed that plume height is proportionate to 0.25-th power of mass flux empirically by analyzing many eruptions. Lighthill (1978) showed that excess pressure due to an acoustic source is proportionate to the rate of change of mass flux. Base on the above studies, by using the infrasound-pressure data we try to estimate the time variation of plume height during the Shinmoedake eruption, January 26 - 27, 2011. Result analyzed by using the infrasound pressure corresponds to plume height variation estimated by weather radar (Shimbori et al., 2013) with high correlation. Best fitting power index is estimated not to be 0.25 but to be 0.35 - 0.41. And coefficient of weight density for plume volume is estimated to be 150 - 300 kg/m^3. If these coefficients could be determined appropriately, infrasound pressure data might be able to estimate the plume height.

Actual successive discharge of pyroclast has two components of mass flux, steady flow and pulsative flow. Steady flow contributes to plume height more than pulsative flow. In this study, even though we estimate it only by pulsative flow's component, calculated result is consistent with observed plume height. It is guessed that there is some kind of linear relation between the two components.

Acknowledgements
We would like to thank Prof. M. Iguchi and Dr. M. Ichihara for precious suggestions.

Keywords: plume height, immediate estimating, infrasound pressure, mass flux, Shinmoedake

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Numerical study on internal structure and turbulent mixing of overpressured jets

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During explosive volcanic eruptions, the eruption clouds form buoyant plumes or dense pyroclastic flows. The critical condition that separates these two eruption styles is primarily governed by entrainment of ambient air into the eruption clouds by turbulent mixing. When turbulent mixing is efficient, the eruption clouds form buoyant plumes, whereas, when it is inefficient, the eruption clouds form dense pyroclastic flows. Recently, it has been pointed out that compressibility of the eruption clouds also influences on the critical condition (e.g., Koyaguchi et al., 2010). When the compressible ejected material is released from the vent at higher pressures than atmospheric pressure (under overpressured conditions), it forms a jet with complex internal structure including rarefaction waves and shock waves. This internal structure affects turbulent mixing between the ejected material and ambient air. Here, we focus on the overpressured eruptions at sonic velocities, and analyze their fluid dynamical features, particularly those of turbulent mixing just above the vent using a three-dimensional numerical model (Suzuki et al., 2005).

In general, as fluid flows from a nozzle at sonic velocities with an overpressure, the fluid undergoes Prandtl-Meyer expansion, rapidly accelerating to high Mach numbers and decreasing in pressure and density. This supersonic flow forms a standing shock wave called a Mach disk perpendicular to the flow just above the nozzle. The high Mach number fluid crossing the Mach disk undergoes an abrupt decrease in velocity to subsonic speeds and increases in pressure and density. A barrel shock is formed surrounding the jet axis and a jet flow boundary is formed outside the barrel shock. An annular supersonic up-flow develops between the barrel shock and the jet flow boundary and maintains its supersonic flow above the Mach disk (e.g., Ogden et al., 2008). According to experimental results by Solovitz et al. (2011), the efficiency of the entrainment of overpressured jets falls to approximately 60% of those in turbulent jets issuing from the nozzle as subsonic flows.

We performed the numerical simulations under the same conditions as those of the experiments by Solovitz et al. (2011): air is issuing from the nozzle into the atmosphere at sonic velocities for an initial temperature of 258 K and for an initial pressure of 2.55 atm. Our results reproduced the complex internal structure with the barrel shock, the Mach disk, the jet flow boundary and the annular supersonic up-flow. As the fluid crosses the Mach disk, its Mach number is reduced from 2.5 to 0.5. The annular supersonic up-flow has a Mach number of about 2.0 and this region with high Mach number is maintained up to ten diameters downstream of the exit.

We also carried out a detailed analysis of our numerical experiment obtained here. We found that eddy structure is formed along the jet flow boundary and these eddies remarkably enhance mixing between the ejected material and ambient air. Solovitz et al. (2011) concluded that the efficiency of entrainment of overpressured jets is reduced on the basis of the properties estimated from averaged values of the column at a given height. However they do not evaluate the effect of local mixing along the annular supersonic up-flow observed in our numerical results. We suggest that the buoyant region generated by the local mixing in the annular supersonic up-flow may stabilize eruption columns.

Keywords: volcano, eruption cloud, numerical simulation, pyroclastic flow

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Frequency analysis of noise around supersonic jet

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Three kinds of noises, turbulent mixing noise, screech noise and broadband shock-associated noise are known to be generated around an under-expanded supersonic free jet [Tam, 1995]. Since screech tone has a sharp peak at a specific frequency and causes problems such as noise pollution and destructive structural fatigue, the generating mechanism and the noise characteristics such as the amplitude and the frequencies have been investigated by many researchers ever since Pawell [1953] first reported its existence. The screech tone is usually generated when the nozzle pressure ratio is in the range of 2 to 6, and most studies of the noise is performed for that pressure ratio range by using microphones. This study is performed in the higher pressure ratio range. Experiments of the sound pressure measurements are carried out by using a microphone. In addition, the density field around the free jet is also visualized by using an optical technique. The flow visualization technique is found to be useful in studying the acoustic noises.

Under-expanded free jet is generated by releasing high pressure air into the atmosphere through a circular hole of 5mm diameter. The air pressure is controlled by a regulator and is measured by a pressure transducer located upstream of the nozzle hole. Jet noises are measured at downstream of the nozzle hole by a condenser microphone (RION UC-54) and the data are stored in PC through the amplifier (RION UN-14). Three different nozzle geometries, straight-type, diverging-type and converging-type are used in the experiment. The optical flow visualization technique of Schrielen method with double optical passage scheme is used. This method has four times more sensitivity compared with the conventional Schrielen technique

From the flow visualization images obtained for the nozzle pressure ratios from 2 to 6, concentric fringes centered at a point downstream from the nozzle exit in the jet are clearly seen. The frequencies estimated from the fringe intervals and the sound speed agree well with those measured with a microphone. This proves the usefulness of the flow visualization in studying acoustic field.

As the nozzle pressure ratio increases, it is observed that the screech frequency and the sound level also decrease. When the ratio is increased beyond 6, no clear peak frequencies are detected. Instead, in this region, it is observed in the flow visualization images that sound waves are generated at around the nozzle exit and propagates in the direction of the jet. The estimated frequencies of the sound waves from the images are beyond the upper frequency limit of our microphone. It is also found from the flow images that the sound wave frequencies extend broad range without clear dependency on the nozzle pressure ratio. These characteristics of the sound wave correspond to those of turbulent mixing noise.

The acoustic pressure measurements with a microphone and the flow visualization technique of double-light-passage Schrielen method are used in this study to investigate the acoustic field around supersonic free jets. Experimental data of the screech tone obtained with the two different methods agreed well and demonstrated that the flow visualization is an useful method of investigating acoustic problems. The flow visualization technique was applied for investigating the noise generated with the high nozzle pressure ratio. It is found that the noises generated in the pressure ratio region are the turbulent mixing noises.

Keywords: Supersonic free jet, Jet noise, Frequency analysis

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Transition in eruption style during the 2011 eruption of Shinmoe-dake: implications from a steady conduit flow model

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Mount Shinmoe-dake, in the Kirishima volcanic group, (located in southern Kyushu, Japan), erupted in January 2011. The eruption was initially magmatophreatic, and then the eruption style underwent a series of transition, from sub-plinian explosions to an extrusion of lava in the summit crater. The purpose of the present study is to investigate the cause of such changes in eruptive styles. We focused primarily on the transition between the sub-plinian and lava extrusion phases, as well as on the termination of lava effusion. To examine the conditions in the conduit and magma chamber, we devised a numerical code based on the one-dimensional steady flow model of Kozono and Koyaguchi (2010), in which a dome-forming eruption is modeled. The model assume that magma ascent as two phases isothermal flow in a cylindrical conduit with vertical and lateral gas escape. The magma viscosity depends on the volatile and crystal content.

Firstly, we systematically searched for a condition in which the magma would not be fragmented, but in which the volatile content would remain constant and unchanged. The magma permeability was estimated to suit that the gas fraction did not exceed the critical value. In this study, we introduced the criterion of Proussevitch *et al*. (1993), in which the critical gas fraction is representatively 0.75. However, calculations using a critical gas fraction ranging from 0.7 to 0.8 showed that the estimated permeability was not sensitive for the critical value. Besides, we tested another fragmentation criterion suggested by Papale (1999), in which occurrence of magma fragmentation depends on the strain rate.

Then we investigated the relationship between the magma chamber pressure and mass-flow-rate under a given magma chamber depth (i.e. conduit length). As the result, we found that reduction of the chamber pressure in the course of the eruption and a subsequent jump in the mass-flow-rate between multiple steady solutions played essential roles for the transition.

Further, we estimated the pressure decrement at the cessation of lava extrusion, and then discussed the total volume of the magma chamber by applying the pressure reduction to the Mogi model. Then we inferred the total volume of the magma chamber as an order of 10^{10} m^3. However, considering that the following processes are probably relevant, our estimation of the chamber volume might be regarded as the upper limit. In other words, volume of the erupted material might be larger than the change in chamber volume which is deduced from the simple deformation model: (a) The rigidity of the host rock just around the magma chamber being lower than that of the ordinary crust; (b) the effect of the compressive property of the chamber magma; and (c) the existence of a co-eruptive supply of magma into the chamber from a depth. At present, no preceding geophysical studies such as the seismic tomography have reported a remarkable anomaly of a comparable size to our estimation at the pressure source of Shinmoe-dake. It suggests that contributions of the above processes may not be negligible. Subsurface exploration with a higher spatial resolution would contribute to a detailed verification of the total chamber volume, as well as the further modeling of the processes listed above.

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Conduit flow dynamics during the 2011 sub-Plinian eruptions of Shinmoe-dake volcano

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The initial phase of the 2011 Kirishima-Shinmoe-dake eruptions is characterized by three sub-Plinian eruptions with forming of eruption columns and tephra dispersion. For these sub-Plinian eruptions, owing to multiple observations such as crustal deformation measurements by tiltmeter, eruption cloud echo measurements by weather radar, and petrological and geological measurements, we have obtained precise information about intensity, duration, magma discharge rate, magma properties and geological conditions. In this study, by incorporating this information into the analysis of conduit flow model, we investigated the conduit flow dynamics during the sub-Plinian eruptions of Shinmoe-dake volcano.

During the sub-Plinian eruptions, there was a good correlation between eruption cloud echo and tilt change. The eruption cloud echo measurements by C-band weather radar (Shimbori and Fukui, 2012) show that 6.5-8.5 km (asl) high eruption columns were continuously formed during the three sub-Plinian events, at about 16:00-18:30 on January 26, and at 1:50-4:40 and 16:20-17:40 on January 27. The borehole-type tiltmeter data by NIED also show clear tilt changes in response to the sub-Plinian events, and the timings of these changes coincide well with those of the formation of the eruption columns detected by the radar echo. Here the source of the tilt change is a spherical deflation source at a depth of about 10 km bsl, implying deflation of a magma chamber caused by migration of magma to the surface. These observations suggest that there was a magma plumbing system connecting a magma chamber at depth and the surface during the sub-Plinian eruptions.

We modeled the magma plumbing system during the sub-Plinian eruptions using a 1-dimensional steady conduit flow model in which bubble flow transits to gas-pyroclast flow at fragmentation surface. In the case of the sub-Plinian eruptions of Shinmoe-dake volcano, magma discharge rate, which is an essential parameter controlling the conduit flow dynamics, has been precisely estimated using geodetic method as about 1.5 x 10^6 kg s^{-1} (Kozono et al., 2013). Under given this discharge rate, we can obtain the relationship between chamber pressure (p_{ch}) and conduit length (L) ("p_{ch}-L relationship") using the conduit flow model, in which conduit flow satisfies the boundary conditions at the chamber and the vent. When this relationship is close to lithostatic pressure-depth relationship, conduit flow is considered to be realistic. We systematically investigated the features of the p_{ch}-L relationship for wide ranges of conduit radius, critical gas volume fraction for fragmentation, permeability for gas escape, and crystal growth rate, under given magma properties at the chamber that are constrained from petrological data. We found that the p_{ch}-L relationship strongly depends on conduit radius, and it is close to the lithostatic pressure-depth relationship in the case that the radius is about 5 m. This indicates that the chamber-surface magma plumbing system during the Shinmoe-dake eruptions was formed by a relatively narrow magma path.

Acknowledgment: We are grateful to T. Shimbori (MRI, JMA) and K. Fukui (KMO, JMA) for providing the data of eruption cloud echo height observed by weather radar.

Keywords: conduit flow, Shinmoe-dake, sub-Plinian eruption, numerical model

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Characteristics of precursory volcanic earthquakes to eruptions at the Showa crater of Sakurajima volcano

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Sakurajima is a post-caldera cone situated on the southern rim of Aira caldera, south Kyushu, Japan. Vulcanian eruptions have occurred at the Minamidake crater at the summit since 1955. Principal eruptive activity shifted to the Showa crater at the eastern flank of the summit in 2006. The eruptions at the crater become active and minor vulcanian eruptions occurred about 1,000 times per year in 2010-2012. Inflationary strain changes are observed by extensometers a few tens of minutes to several hours prior to the eruptions and are caused by pressure sources located at depths of 0-1.5 km (Iguchi et al., 2013). The inflation rates decrease or sometimes suspend about 30 minutes before the eruptions. Small earthquakes dominated by high frequency components (5-6 Hz) swarm when duration of inflation is longer than 1 hour. The earthquakes begin to occur a half hour to 1 hour after the start of the inflation. The amplitudes and number of the earthquakes further increase when the inflation rates decrease or suspend. And, the occurrences of the earthquakes suddenly stop at the start of the eruptions. The occurrences of the earthquake swarms are related to the decrease of inflation rate and the long inflation. The hypocenters of the earthquakes are located at a depth of 0.5 km beneath the crater and are close to depth of the pressure source. The precursory earthquakes may be generated by release of excess pressure accumulated by inflation of the pressure source. The earthquakes are similar to BH-type earthquakes during the eruptive activity of the Minamidake crater in waveforms and relation of the inflationary deformation, however the earthquakes are different in amplitude, patter of occurrence and direct precursor of eruptions.

Keywords: Sakurajima volcano, explosive eruption, precursory earthquake

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Evidence of permeable gas transport in magma from obsidian pyroclasts

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Permeable gas flow through connected gas bubbles in magma is thought to control the rate of outgassing from silicic magma and hence the style and explosivity of volcanic eruptions. Recent experimental studies (Okumura et al., 2009; Caricchi et al., 2011) demonstrated that gas permeability in magma starts to increase at a vesicularity of ca. 30 vol%; this vesicularity can be achieved at a depth of a few kilometers for typical rhyolite magma. This result supports the field observations of volcanic gases that indicate outgassing from magma at depths of a few to several kilometers (Edmonds et al., 2003; Ohba et al., 2008). In addition to these experiments and observations, this study exhibits that permeable gas transport occurs at a depth of a few kilometers on the basis of volatile content and bubble microstructure in obsidian pyroclasts.

In this study, obsidian pyroclasts were collected from the Kemanai pyroclastic flow deposit of the Heian eruption at Towada volcano. The obsidians were doubly polished and its water contents were measured using FT-IR microspectrometer. Obsidian pyroclasts were divided into two major groups, i.e., clear and dark brown obsidians. Clear glassy fragments include deformed and elongated bubbles and some fragments show banding structure. The bands with brown color seem to be formed along highly elongated bubbles but the bands continue even if the bubbles disappear. The composition of major elements is the same in clear and brown parts. In contrast, water content profiles perpendicular to the bands show the increase in water content from 2 wt% in the clear part to 3-4 wt% in the center of brown bands. The concentrations of hydroxyl group and molecular water show positive correlation and the equilibrium temperature (quenched temperature during cooling process) estimated from water speciation is approximately 500 degC. The width of hydration layer is 70-100 um, which can be explained by diffusion time of 100 ky, 7 hrs and 5 min at temperatures of 25, 500 and 1000 degC, respectively.

The analytical results of this study indicate that the hydration occurred at temperatures $>$500 degC. When we assume magma temperature of 1000 degC (Hunter and Blake, 1995), the depth at which hydration occurred is estimated to be 1600 m (40 MPa) on the basis of water content of 2 wt%. Because the hydration layer has high water content (3-4 wt%), permeable gas transport is expected to occur even at deeper part. If magma temperature decreases before the hydration, the estimated depth at which hydration occurred may be shallow (600 m at magma temperature of 500 degC). However, bubble collapse and space disappearance along brown bands imply that magma temperature is high enough to heal bubble networks even after the hydration. If magma temperature is 500 degC, healing timescale is $>$100 yrs (Yoshimura and Nakamura, 2010). This timescale is much longer than the timescale of volcanic eruption and water diffusion profile in the bands would be annealed during the healing. Therefore, magma hydration is inferred to be induced by permeable gas transport at a depth of a few kilometers.

Keywords: obsidian pyroclast, permeable flow, gas transport, magma, water

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Magma permeability and magma-slurry mingling during the 1963-67 eruption

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Processes observed during the extremely well documented eruption of Surtsey, Vestmanyaar, Iceland, 1963-67, highlighted the effects of interaction between erupting magma and abundant seawater on eruption dynamics. As the 50th anniversary of this canonical eruption approaches, however, many specific aspects of the eruption dynamics remain only qualitatively characterized. We present a detailed micro-cT 3D textural analysis of lapilli and ash from Surtsey, and use mingling and thermodynamic theory to quantitatively describe Surtseyan jets.

Fine lapilli (-2.0 phi) have total porosity ranging from 24 to 59 % (with one dense, impermeable outlier of 6 %), > 98 % of which is connected. Bubble number densities range from 4.05x105 to 8.30x106 cm-3, and are roughly inversely proportional to porosity. Darcian permeability ranges from 2.95x10-13 to 3.87x10-11 m2. Ash particles (3.0-3.5 phi) are generally blocky in outline, with surfaces often bounded by broken vesicles on one or more sides; however, blocky particles lacking any sign of vesiculation are also present. Groundmass textures vary from nearly holocrystalline tachylite to hypocrystalline sideromelane, with many larger clasts having a transitional texture characterized by patches of both.

Nearly all the lapilli have ash-packed vesicles around their exteriors. Such ash could easily have been entrained mechanically during transport, deposition and/or reworking, or drawn into the exterior vesicles by capillary action. More enigmatic, however, is when the vesicles deep within lapilli contain fine ash particles, ranging from a few grains adhering to vesicle walls, to cases where the vesicles are densely packed with poorly-sorted ash.

Based on careful examination of textures, we explore the hypothesis that a proportion of the ash in lapilli may in fact have been entrained during hydrodynamic mingling of magma erupting through a slurry of previously-erupted material in a flooded vent. We use such a scenario to explain the typical Surtseyan cypressoid jets of steam and pyroclasts. The slurry entrained into the newly erupted pyroclasts was vapourized to steam by magmatic heat, and then discharged from the same pyroclasts during dispersal.

Analyses based on thermodynamics and fragmentation criterion suggest that for a narrow but plausible range of magma porosity and magma-slurry mingling regimes, entrainment and vapourization of slurry may also have assisted in driving part of the fragmentation process. The hypothesis presented here is consistent with classical qualitative models of Surtseyan jet dynamics, and works toward explaining specific details about how magmatic and external factors contribute individually and cooperatively to shallow subaqueous eruption dynamics.

Keywords: magma, permeability, magma-water interaction, Surtsey, microtomography, mingling

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Water control on variation in eruptive style during the first eruptive episode of the Barombi Mbo Maar, Cameroon

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The first eruptive episode of the Barombi Mbo Maar is represented by about 60m thick pyroclastic material. Approximately 20m of this display a contrasting bedding and grading in sustained thinly well-bedded succession of ash- and lapilli-beds, low concentration turbulent pyroclastic flow, bombs- and highly vesiculated scoria-rich bed, and lithic- and xenolith-rich explosive breccia, while the other part, under the lake level is mainly covered by the vegetation. The sequence of volcanic activities that sustained the settling of these materials developed subsequently in four eruptive phases: phreatic ? phreatomagmatic - strombolian - phreatomagmatic. This variation in eruptive style is consistent with recent studies of the deposit stratigraphy, regarding lithofacies from individual accessible beds of the deposit unit, the grain-size distribution and the componentry. Our results suggest that eruption style changes can be interpreted as follows: initially, a rising magma interacted with potential surface water coming from the collapse of part of an ancient maar wall to produce series of phreatic eruption. The scar of this older maar visible at the west of the Barombi Mbo Maar is consistent with this observation. Assuming that the volume of water was important, the phreatic activity continuously produce ash and lapilli and ended with a phreatomagmatic style represented stratigraphically by a pyroclastic surge. In the course of the eruptive activity, water might have become exhausted giving rise to a more strombolian style mixed by phreatomagmatic material, as suggest by the presence of several centimeter- to decimeter-sized of spatter bombs and vesiculated scoria, mantle xenoliths and country rocks above the surge layer. The eruption would have generated cracks in the basement rocks through which water was re-supplied into the hydrothermal system after a short repose period. Then a new magma source interacted with the groundwater and the phreatomagmatic activity continued with more violence, unraveling the crystalline basement to produce the phreatomagmatic ash, mantle xenolith and country rock fragments-rich explosive breccia.

Keywords: Barombi Mbo Maar, Eruptive styles, Phreatomagmatic eruption, Strombolian activity, Stratigraphy, Cameroon

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Petrological comparison between the earliest product of Aso-4 pyroclastic flow and its precursory lava extrusion, in cen

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Oyatsu pumice flow represents the earliest stage of Aso-4 pyroclastic eruption (89 Ka) that produced Aso caldera, and shows an interesting contrast with precursory extrusion of Takyubaru lava flow (90 Ka). The petrological comparison of the two magmas will provide important information of the magma supply system that lead to an ultra-Plinian eruption.

Both Oyatsu white pumice flow deposit and Takayubaru lava have phenocryst assemblage of plagioclase, clinopyroxene, orthopyroxene, hornblende and opaque minerals. However, Takayubaru lava contains opacitized hornblende and fractured plagioclase.

Both Oyatsu white pumice and Takayubaru lava show short but well-defined fractionation trends in the compositional plots. However, the former does not plot on the extension of the latter trend. This indicates Oyatsu and Takayubaru magmas do not show genetic relationship by fractional crystallization.

Bulk distribution coefficients estimated from the logarithm plots of trace elements (e.g. log(Rb)-log(Sr), log(Rb)-log(Zr), log(Rb)-log(Ba)) are different between Oyatsu pumice and Takayubaru lava. Thus although the phenocryst assemblage is the same, the proportion of subtracted phases seem to be quite different.

We conclude that the precursory Takayubaru magma did not form a part of huge Aso-4 magma supplying system which erupted Oyatsu pumice.

Keywords: Aso-4 pyroclastic flow deposits, Takayubaru lava, magma supplying system

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Mechanism of delayed fragmentation of vesicular magma by decompression

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The fragmentation of vesicular magma is a key phenomenon to determine the style of volcanic eruption. To understand the magma fragmentation, we performed a rapid decompression experiment using bubbly syrup as an analogous material of vesicular magma. We classify the onset of fragmentation using a measure of brittleness (critical brittleness) at the bubble surface at the time when the differential stress at the surface reaches the critical fracture stress. In our case, the brittleness is unity when the response of material is brittle. It is 0.5 when the material response is completely ductile. The results are summarized as follows: (a) Brittle fragmentation occurs when the critical brittleness close to unity when the differential stress reaches the critical stress; (b) No fragmentation occurs when the critical brittleness is close to 0.5 if the differential stress is slightly larger than the critical stress. In addition to the classifications (a) and (b), we find the other class: (c) Delayed fragmentation occurs even if the critical brittleness indicates the ductile response of the material when the differential stress sufficiently exceeds the critical stress.

The delayed fragmentation occurs within the characteristic time of bubble expansion in viscous liquid, while its onset is after the relaxation time of viscoelastic material. This means that the delayed fragmentation is brittle-like (solid-like) fragmentation. Magma fragmentation may be viewed as sequential brittle-like fragmentation (Kameda et al. JVGR (2012), submitted).

To understand the cause of the delayed fragmentation, we tested the response of a large number of samples, which vary in brittleness, volume, bubble diameter, void fraction, and porosity distribution. The volume of samples is selected from 25 ml (small) or 100 ml (large). The void fraction is in the range of 3 to 28%.

From the experiments with small volume of samples, we observed some of samples exhibit no fragmentation even if their critical brittleness was about 0.9. All the samples with large volumes fragment when the brittleness was 0.9. The pore distribution of the small samples is more uniform than that of large samples. Therefore, stress concentration in the small samples is weaker than that in the large samples.

Next, we evaluated the influence of bubble diameter to the response of the sample. We generated the oxygen bubbles in the sample using hydrogen peroxide and manganese dioxide as a catalyst. We controlled the bubble diameter by changing the temperature of the syrup when we added the manganese dioxide. The response of two samples with different bubble was observed diameters simultaneously placed in the decompression facility. The observation indicates the response of two samples is identical. Therefore, average bubble diameter does not affect the onset of fragmentation.

We find that fragmentation does not occur in the sample with the void fraction less than 8% whose critical brittleness is about 0.9. Then, we observed the response of the sample with low void fraction but in which a large volume of cavity was artificially created. This sample fragments.

The critical brittleness was calculated using the differential stress on the bubble surface under the assumption of uniform pore distribution. Our experiments indicate that this calculated value may inadequate to evaluate the fragmentation. The true value of brittleness required to the onset of brittle fragmentation should be close to unity. Our experiments also suggest that the delayed fragmentation observed with lower value of the critical brittleness is caused by non-uniform pore distribution, which leads to increase the local differential stress and brittleness in the sample.

Keywords: fragmentation, viscoelasticity, analogous experiment, brittleness

SVC50-P13 Room:Convention Hall Time:May 20 18:15-19:30

Experimental determinations of water solubility in the Shinmoe-dake 2011 dacite melt to 150 MPa

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Water is the first dominant volatile within a volcano, and hence its solubility in a melt is fundamental to how explosive the eruption will be. Published solubility data for water are rather sparse, particularly for moderate SiO2 content melts, however. This has resulted in insufficient data coverage in composition space, rendering water solubility not to be precisely modeled if a melt is subject of partial crystallization (hence of composition change).

In this study, water solubility in dacite melt (68.3 wt% SiO2) was experimentally determined at 1000 degree C and 50-150 MPa in an internally heated pressure vessel. A groundmass separate of white-colored pumice from the 2011 eruption of Shinmoe-dake, Kirishima volcano group, was equilibrated with O-H fluid, and the water content in the quenched glass was determined by near-infrared spectroscopy. Oxidation-reduction state was controlled to near the Ni-NiO buffer, so that the O-H fluid was present as nearly pure H2O (more than 99 mol%). Temperature condition of 1000 degree C was desired since the water-saturated liquidus was experimentally located between 950 and 1000 degree C at the pressure range 50-150 MPa.

Experimental result shows that at 1000 degree C, the water solubility in the dacite melt monotonously increases with pressure, from 4.4 plus-minus 0.3 mol% (2.4 wt%) at 50 MPa through 6.0 plus-minus 0.3 mol% (3.3 wt%) at 100 MPa to 6.8 plus-minus 0.3 mol% (3.9 wt%) at 150 MPa. These values are practically the same as the previously published solubility data for water in rhyolite melts at 1000 degree C (4.2 mol% at 50 MPa, 6.3 mol% at 100 MPa; Yamashita, J. Petrol., 40, 1999). Thus, the water solubility was insensitive to the change of melt composition during groundmass crystallization in the Shinmoe-dake 2011 eruption. This would provide a rigorous petrological base for quantitatively modeling of degassing/explosive behavior in the Shinmoe-dake 2011 eruption as a continuum problem.

Keywords: water, solubility, silicate melt, dacite, infrared spectroscopy, high-pressure and high-temperature experiment