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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

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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