Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SVC047-01 Room:301B Time:May 24 08:30-08:45

A combined model of conduit flow and eruption cloud dynamics. Part 3. 3-D simulations of eruption column dynamics

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In order to predict the transition of eruption styles (e.g., plinian eruption to pyroclastic flow) during explosive volcanic eruptions on the basis of geophysical observations such as ground deformation around erupting volcanoes, we are developing a combined model for conduit flow and eruption cloud dynamics. We consider a conduit which flares with a certain opening angle at the vent, and systematically investigate the dynamics of conduit flow and eruption column. So far, we have obtained the relationship between the mass flow rate at the crater base and the magma chamber condition (depth and pressure) in Part 1, and the relationship between the quantities (radius, pressure and velocity) at the crater top and the mass flow rate at the crater base in Part 2. Here, we discuss the effects of crater shape on the condition of the generation of pyroclastic flow (column collapse condition) on the basis of 3-D numerical simulations of eruption column dynamics, in which the conditions at the crater top are given as boundary conditions.

When magma properties (e.g., water content and temperature) are fixed, the column collapse condition has been considered to depend primarily on magma discharge rate (e.g., Carazzo et al., 2008). When a crater is present, however, the radius, pressure and velocity at the crater top change depending on the crater shape, which, in turn, affects the column collapse condition. In this study, we investigate how the column collapse condition changes with crater shape in the parameter space of radius and pressure at the crater top (the r-p space). According to Koyaguchi et al. (2010), the flow in/above the crater is divided into 4 regimes in the r-p space: (1) sonic flow choked at crater top, (2) under-expanded supersonic flow, (3) over-expanded supersonic flow, and (4) subsonic flow. The boundary between (2) and (3) is defined as correctly expanded supersonic flow. For a given mass discharge rate, the flow regime changes from (1) to (4) as the radius increases and the pressure decreases at the crater top.

The results of 3-D simulations indicate that the eruption columns of the flow regimes (1) and (2) accelerate due to decompression just above the crater, whereas those of the flow regime (3) decelerate at a series of shock waves; as a result, the eruption columns of the flow regime (3) are more likely to collapse and generate pyroclastic flow for a given magma discharge rate. Combining these results and those of Part 2 leads to a conclusion that the generation of pyroclastic flow can be caused by an increase in opening angle of crater even for a constant magma discharge rate.

The column collapse condition obtained in the present study quasi-quantitatively agrees with that based on the 1-D steady decompression model at the crater (Woods and Bower ,1995; Koyaguchi et al., 2010) and the 1-D steady eruption column dynamics model (e.g., Bursik and Woods, 1991). We can observe additional features from the present 3-D simulation results. For example, the 3-D structure of jet around the transitional state between eruption column and pyroclastic flow is different between the flow regimes (2) and (3). In the flow regime (2), an annular unstable up-flow develops at the edge of jet, which enhances mixing between ejected materials and ambient air, and hence, stabilizes the eruption column. On the other hand, in the flow regime (3), the transitional state between eruption column and pyroclastic flow is characterized by an annular down-flow, which generates a small-scale pyroclastic flow, while the central part of the jet forms a stable buoyant eruption column.

Keywords: volcanic eruption, simulation, eruption column, pyroclastic flow, crater, fluid dynamics

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3-D numerical simulations of eruption clouds: the critical condition for column collapse

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During an explosive volcanic eruption, an eruption cloud generates either a buoyant eruption column or a pyroclastic flow. The mixture of hot pyroclasts and volcanic gas is released from the volcanic vent into the atmosphere. The density of the mixture is several times larger than atmospheric density. As the ejected material entrains ambient air, the density of the mixture decreases because the entrained air expands by heating from the pyroclasts. If the density of the mixture becomes less than the atmospheric density before the eruption cloud loses its upward momentum, a buoyant plume rises to form a plinian eruption column (column regime). On the other hand, if the mixture loses its upward momentum before it becomes buoyant, the eruption column collapses to generate a pyroclastic flow (collapse regime). In order to understand and predict the critical condition that separates these two eruption styles (i.e. column collapse condition), we have performed a series of three-dimensional numerical simulations.

In this study, we identified two types of column collapse in the simulations: jet-type and fountain-type collapses. In general, the entrainment of ambient air by the ejected material is driven by shear between the cloud and air at the edge of the column; consequently, a concentric structure consisting of an inner flow (i.e. potential core) and an outer shear layer is developed. The potential core is eroded by the outer shear layer as the downstream distance from the source increases; the length of potential core increases as the vent radius increases. If the cloud does not become buoyant before the outer shear layer reaches the central axis of the flow, the cloud with a high concentration of the ejected material generates a fountain structure and collapses to the ground (i.e. fountain-type collapse). On the other hand, if the cloud does not become buoyant after the potential core disappears due to erosion by shear, the cloud which mixes well with the ambient air generates structure similar to the turbulent jet and collapses as a pyroclastic flow (i.e. jet-type collapse).

When the exit velocity is fixed, the transition from eruption column to pyroclatic flow occurs as the mass discharge rate (i.e. vent radius) increases. This transitional condition (i.e. the column collapse condition) is determined by a critical mass discharge rate (MDR_{CC}). In addition, whether the potential core disappears or not is also determined by another critical mass discharge rage (MDR_{JF}). According to the flow regime maps obtained from our simulations, which type of collapse (fountain-type or jet-type collapse) occurs in the transition depends on whether MDR_{CC} is larger or smaller than MDR_{JF}. When the magma temperature is low, MDR_{CC} is smaller than MDR_{JF}; the jet-type collapse occurs in the transition. In this case, the column collapse condition depends only on the Richardson number. When the magma temperature is high, on the other hand, MDR_{CC} is larger than MDR_{JF}; the fountain-type collapse occurs in the transition. In this case, the collapse condition depends not only on the Richardson number but also on the Mach number. When the flow is supersonic (the Mach number is larger than 1.0), the standing shock waves developing in a fountain inhibit the entrainment of ambient air, which enhances column collapse.

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

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Modify of Tephra2 and a test run using the 1986 eruption of Izu-Oshima volcano

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Tephra2 is a simulation program based on the advection diffusion model of Suzuki, 1985; Macedonio et al, 1988, and developed as a tool for probabilistic hazard modelling (Connor et al., 2001; Bondadonna et al., 2005). This code characterizes the plume using a vertical column model and application of inversion techniques show the code's potential in reconstructing ancient eruptions. In previous studies, column reconstruction seemed to successfully model the simple vertical plume of the 1992 eruption of Cerro Negro, Nicaragua (Connor and Connor, 2006); however, the model failed to uniquely constrain the column height for a larger eruption, the 2450 BP eruption of Pululagua, Ecuador. This discrepancy reflects that tephra fallout during the most energetic eruptions takes place from the base of a horizontally spreading umbrella cloud as shown in studies based on the gravity current models rather than randomly from the uprising column. We have modified the Tephra2 code to include fallout from the umbrella cloud. We also implement the Suzuki function to calculate the probability of particle release as a function of height. In the presentation, application to the 1986 Izu-Oshima eruption will be shown as a test case.

Keywords: Tephra2, volcanic ash, simulation, advection diffusion model, Izu Oshima volcano, volcanic plume

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SVC047-04 Room:301B Time:May 24 09:15-09:30

Acoustic resonant oscillations between the atmosphere and the solid earth during the 1991 Mt. Pinatubo eruption

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Long-period harmonic Rayleigh waves were observed on seismometers during the 1991 Mt. Pinatubo eruption in the Philippines. The amplitude spectrum of the Rayleigh waves shows two distinct peaks at periods of about 230 and 270 s. In the Earth's atmosphere, long-wavelength standing acoustic waves are bounded in a low-sound-velocity channel between the thermosphere and the ground. The Rayleigh waves and the fundamental and first overtone of atmospheric acoustic waves trapped in the low-sound-velocity channels have approximately the same horizontal wavelength and frequency at periods of 230 and 270 s, respectively, i.e., the atmosphere and the solid earth satisfy the condition for acoustic resonant oscillations. The standing atmospheric long-wavelength acoustic waves set off by the eruption selectively excited seismic spheroidal modes near the resonant period through acoustic resonant coupling and resulted in harmonic Rayleigh waves. In contrast, gravity waves and Lamb waves (atmospheric boundary waves) do not couple to the ground efficiently and are not easily observed as ground disturbance on seismograms during volcanic eruptions.

Keywords: Rayleigh waves, Mt. Pinatubo eruption, resonance between the atmosphere and solid Earth,, harmonic ground motion, air-ground coupling, anomalous excitation of spheroidal mode

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SVC047-05 Room:301B Time:May 24 09:30-09:45

Volcano deformation caused by gas slug ascent in an open conduit

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Volatile behavior in magma is a key to understand the dynamics of volcanic eruption. Recent geodetic observations at active volcanoes that erupt with Vulcanian or Strombolian type have succeeded in detecting volcano inflation prior to each explosion. Simple numerical simulation dealing with high viscous two-phase magma flow shows that temporal changes of volcano deformation are much affected by gas bubble growth in magma (Kawaguchi et al, 2009, AGU). Eruptions characterized by low viscous magma, such as Strombolian type eruptions, however, accompany the relative motion of gas bubble and liquid magma. These eruptions are considered to be generated by a sudden release of a large gas slug. In this study, we focus the Strombolian type eruption, and examine the temporal changes of volcano deformation due to such slug ascent process.

In low-viscous magma, gas bubbles close each other, and form the slug flow which include large gas bubbles intermittently. Here, we model a gas slug ascent process according to the Canonical static pressure model (James et al., 2009). We consider the cylindrical conduit with a constant diameter. There is one slug in the conduit. The gas pressure in the slug is equal to the sum of atmospheric and static magma pressures. The slug base ascends with a constant velocity determined from the conduit diameter and dimensionless Froude number. As the slug ascends in the conduit, the slug pressure decreases and the gas slug volume expands. Using the mass conservation law of liquid magma and gas in the slug, temporal changes of the slug length and magma head depth are calculated.

Magma pressure increases with depth according to the bulk density: the slug part is low density so the pressure gradient is small while the other part, that consists of melt, is characterized by large pressure gradient. As a result, ascending slug acts as a deflation source, while magma head rises due to volume expansion of slug and acts as inflation source. We calculate the radial and vertical displacement and tilt changes due to the slug ascent, assuming an open conduit and elastic half-space.

We examine the temporal changes of volcano deformation due to the slug ascent for the low-viscosity basaltic magma. We examine the temporal changes of volcano deformation due to slug ascent. At the station near to the vent, radial and vertical displacement and tilt changes show inflation, during slug ascent process. While at a station far from the vent, first, the displacement and the tilt show inflation. However, when the slug reaches the shallow part of the conduit, the inflation rate of radial displacement decreases and the vertical displacement and the tilt turn into deflation. Because, as slug ascends conduit, the effect of deflation source increases.

Our simulation results indicate that temporal changes of volcano deformation due to the gas slug ascent are affected by slug depth and distance from vent to a station. Because there are inflation and deflation source in the conduit at different depth. Observation data of time variation of volcano deformation at different distances can be used to estimate the slug depth.

Keywords: magma ascent, slug flow, open conduit, volcano deformation

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Effects of lateral gas escape on transitions from lava dome eruptions to explosive eruptions

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During lava dome eruptions, gas phase can escape from magma in two different ways: lateral gas escape through the conduit wall and vertical gas escape through the magma to the vent. The competition between these gas escapes and vesiculation of magma leads to complex features of conduit flow such as a transition to explosive eruptions. In this study we investigated how the gas escapes control the dynamics of lava dome eruptions on the basis of a steady or time-dependent 1-dimensional conduit flow model in which both the lateral and vertical gas escapes are taken into account.

Transitions from lava dome eruptions to explosive eruptions can be predicted by the relationship between pressure at magma chamber (p) and magma flow rate (q) at steady state (referred to as the p-q curve). The conduit system is stable when the slope of the p-q curve (dp/dq) is positive, whereas it is unstable when dp/dq is negative. We systematically investigated the features of the p-q curve on the basis of the steady conduit flow model. Results show that the p-q curve is sigmoidal under some realistic conditions: dp/dq is positive in the low-q and high-q regimes, and it is negative in the intermediate regime. In the low-q regime, the magma porosity inside the conduit is extremely low because of effective lateral and vertical gas escapes. This regime corresponds to the conduit flow of stable lava dome eruptions. The conduit flow in the high-q regime, on the other hand, is characterized by a high porosity. In this case the effect of lateral gas escape is negligibly small compared with that of vertical gas escape.

We investigated the time evolution in the features of the conduit flow in the case that the p-q curve is sigmoidal on the basis of the time-dependent conduit flow model. This model assumes that the change in the pressure at the magma chamber is controlled by the balance between magma supply from depth to the magma chamber and magma effusion from the chamber to the conduit. Our results show that, because of the sigmoidal shape of the p-q curve, magma discharge rate abruptly increases from the low-q to high-q regimes as magma supply gradually increases at depth; this jump corresponds to a transition from lava dome eruptions to explosive eruptions. This implies that the transition of eruption styles is associated with the change from lateral gas escape to vertical gas escape.

Keywords: lava dome eruptions, gas escape, transition of eruption styles, magma ascet, conduit flow, numerical model

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Long-period seismic events induced by quick bubble formation: a new source mechanism predicted by SPH simulations

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Long-period seismic signals whose periods are several seconds or longer are often observed in active volcanoes and suitable interpretations of these signals are expected to give important information about underground volcanic activities. In fact, the source process that causes long-period oscillations is not always understood satisfactorily. If elastic resonance produces such long-period oscillations the resonator must have sizes of kilometers (Fujita and Ida, 1999; Fujita et al., 1995) which are not usually compatible with known structures of volcanic interiors. Fluid-filled cracks can be a source of long-period oscillations with smaller sizes (Chouet, 1986; Ferrazini and Aki, 1987) but they are not well fit to axial symmetry that is required for such seismic events as observed at Miyakejima volcano in 2000 (Kobayashi et al., 2009). In this context a new mechanism of long-period oscillations is proposed here based on computer simulations in an SPH (Smoothed Particle Hydrodynamics) method.

The SPH method is one of the particle dynamics in which deformation and flow of materials are analyzed based on motions of particles subjected to suitable mutual interactions. Compared with other particle dynamics like DEM (Discrete Element Method) an important character of the SPH method is that interactions between particles are determined using the same physical concepts and the same equations as in corresponding continuum mechanics. Namely, velocity, density, stress and other physical properties are allocated to each particle and the relations that control the state and motion of particles are derived from the equation of motion and constitutive equations that hold for continuums. In this paper the SPH method has been further developed so as to apply to magmatic processes involving the effects of included volatile components. In particular, the particles that represent magma are assumed to meet the equation of state for bubbly magma when some of the volatile component has deposited as bubbles.

If some area of magma is over-saturated with volatile components this area should be released from the over-saturated condition sooner or later and should form bubbles in it with almost instantaneous volume expansion at that time. Our numerical experiments in the SPH method have revealed that quick bubble formation can induce long-period oscillations of the fluid system. The oscillations attenuate slowly and disappear after about ten cycles. The numerical experiments further point out that the long-period oscillations are realizable when the magma system has both a very compressible bubbly area and a free surface. The period of oscillations that has been obtained from the numerical experiments is about two seconds for the magma system that contains a bubbly area of radius 5m in a 50m-wide normal fluid with a density, viscosity, bulk modulus and volatile solubility similar to real magmas.

A simplified model of the long-period oscillations has been constructed based on the numerical experiments. In this model the fluid system is treated as consisting of the upper part participating in vertical rigid motions and the other lower part that transmits pressure between the upper part and the bubbly compressible area. An arithmetic expression of the period of the long-period oscillations is given by the model and predicts that the period depends on gravitational acceleration as well as an effective bulk modulus of the bubbly area and sizes of the fluid system. The model may be useful in getting an intuitive idea of the source process and applying it to observed long-period seismic events.

Keywords: long-period seismic event, volcanic earthquake, magma, bubble formation, SPH method, computer simulation

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SVC047-08 Room:301B Time:May 24 10:15-10:30

Coupling between the fluid system oscillation equation and Rayleigh-Plesset equation

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In order to the coupling between the fluid system oscillation and the excitation source, we have formulated the governing equations describing the fluid flow in the conduit and the overpressure in fluid chamber below the conduit, In this talk, we employ the bubble oscillation as the excitation source, which is described by the Rayleigh-Plesset equation.

The equations include the friction term, Helmholtz oscillation term, gravitational recovery oscillation term and the coupling factor. The coupling factor represents the geometrical scale relationship among bubble and conduit: (bubble size x conduit length)(/conduit cross section). Numerical solution for the case that a bubble instantaneously has the overpressure shows that 1) the bubble oscillation excites the oscillation of fluid system, 2) in the case of large coupling factor, the energy transfer from bubble oscillation to the oscillation of fluid system, 3)the condensation and evaporation of gas in bubble damp the oscillation of fluid system, 4)in the case of large coupling factor, the fluid oscillation continues even if the bubble oscillation disappears, 5) the fluid oscillation excited by the bubble oscillation gets into the regime of damped oscillation even if the system is in the regime of over damping as the ordinary condition. From these results we speculate that in the experimental geyser the coupling between bubble oscillation and fluid system oscillation effectively works due to the coupling factor, whereas the coupling in natural geysers and volcanoes depends on the geometry of conduit and bubble size.

Keywords: bubble, Rayleigh-Plesset equation, tremor equation, geyser, low-frequency earthquake

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Ascending seismic sources associated with an explosion and tremor and their implications for volcanic conduit dynamics

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Application of seismic techniques to an explosion event at Tungurahua volcano, Ecuador, provided clear images to elucidate its source process. We used waveform inversion and a source location method to analyze the event observed by five broadband seismic stations on the volcano. The source location method assumes isotropic radiation of S waves, which has been shown to be valid in a high frequency band because of the path effect caused by the scattering of seismic waves. The source location method using seismic amplitudes in a frequency band of 5-10 Hz indicates that the event was triggered at a depth of 6 km below the summit, and the source ascended toward the summit at a speed of about 1600 m/s. Waveform inversion of low-frequency signals in a period band of 2-10 s at the event onset points to an isotropic mechanism with initial deflation and subsequent inflation at a similar depth of 6 km. This source-time history can be explained by a sudden pressure drop and subsequent bubble growth in magma. Similar ascending sources were estimated during tremor associated with sustained eruptions. The ascending sources suggest that a pressure wave generated by the growth of bubbles travelled up the magma conduit, which triggered fragmentation of magma at shallow depths. Our study suggests that a pressure disturbance in magma at depth and its upward propagation are fundamental processes to trigger eruptions.

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Source mechanisms of vulcanian eruptions at Semeru volcano, Indonesia, as inferred from seismic and tilt data analyses

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We analyze tilt records and broad-band seismic signals preceding or associated with vulcanian eruptions observed at the summit of Semeru volcano, Indonesia. Signals from a tilt meter (701-2 Applied Geomechanics) and a STS-2 seismometer (Streckeisen Ltd.) installed at a depth of 1 m are recorded at a temporal station located at about 500 m north from the active crater. More than 1000 explosions are well recorded on March and April in 2007. To know how the volcano inflation changes with eruptions, we examine temporal changes and amplitudes in tilt and seismic signals. We first classify the magnitude of each explosion into five categories according to the maximum amplitude of the velocity seismogram of the explosion earthquake. Then, we stack the tilt signals, adjusting the time to the initial motion of the explosion earthquake, to obtain an average view of the volcano inflation. The stacked tilt records show that gradual uplifts toward the active crater star about 200 to 300 s before each explosion. The uplifts accelerate with time, especially about 60 s before the explosions. There is no significant dependence on the magnitude of explosion in these time scales. On the other hand, the amplitude of tilt increases with increasing the magnitude of explosion. This strongly suggests that we are principally able to predict the magnitude of explosion from the geodetic measurements. We further examine the broad band seismic signals of explosion earthquakes to obtain the average processes of vulcanian explosion. According to the maximum amplitude of the explosion earthquakes, we stack the vertical component signals that are low-pass filtered at 0.5 Hz. The averaged signals show downward motions for about 5 s followed by upward motions. The amplitudes of upward motions are much larger and longer. This means that the volcano first deflates, and then inflates. The source depths are not determined yet, but are maybe withdrawal of magma in the conduit, and rapid supply or expansion of magma remained in the conduit. Although the stacked signals changes about 6-8 times in amplitudes, we do not see any significant differences in the temporal changes. These tilt and seismic data analyses indicate that the vulcanian explosions repeatedly occurring at Semeru volcano are mainly different in the magnitude, but not in time scale.

Keywords: Vulcanian, explosion, tilt, explosion earthquake, inflation, deflation

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Mechanism of the 1888 Phreatic Explosion at Bandai Volcano, 3. Location of Explosive Source and Multi-directed Outbursts

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The eruption at Bandai volcano in 1888 has been known as one of the most gigantic phreatic explosions. The details of this eruptive process as well as the seismic precursory have been collected by the local habitants around the volcano. The eruptive mechanism has been studied on the basis of old documents such as eyewitnesses, sketches and photographs. However, the lacking of underground data has led volcanologists into some misconstructions and unclear understanding of the processes until now. We looked back on the basic factor in the phreatic outbursts based on the informations both from the 3D shallow structure and from the seismic activities that were obtained after one century since the eruption.

Sekiya and Kikuchi (1890) reported that the phreatic explosions occurred almost simultaneously to the directions of up-, north- and southeast-wards. The upward directed explosion followed one after another in 15 to 20 times. The northward one discharged horizontally a large quantity of debris avalanche that was triggered by the mountain collapse. Terrible blast of winds in addition to high speed mud stream burst downward to the southeast along the Biwasa valley. Sekiya and Kikuchi (1890) explained that the phreatic materials were stored beneath Kobandai-san and that the flows of outburst happened at the same place and took merely different routs. This likely explanation has been received as a commonly accepted model for the explosive process and has been cited in many articles (e.g. Moriya, 1980). However, several observed facts seem to be out of harmony with this model.

In this study, referring the 3D velocity structure (Yamawaki et al., 2004) and the recent seismic activities (Nishimura et al., 2002), the explosive source was modeled by a pressurized cavity in a semi-infinite elastic body. The internal pressure in a cavity produces characteristic stress distribution along the periphery of cavity and also along the free surface (Savin, 1961).

Two maximum tensile stresses are induced locally in this model. The one maximum tensile stress is located on the free surface just above the apex of the cavity and the other does on the periphery of the cavity. The latter position is determined by the ratio d/r, where r is the radius of the cavity and d is the distance to its center from the free surface. Appling this model to the actual velocity structure, the projected position (point A) of the apex onto the free surface is located at Numano-taira about 500m NE-ward from the summit of Obandai-san. By reference to the spatial distribution of the asismic region, the parameters of d and r are fixed to be 1km and 0.5km respectively and the maximum tensile stress along the periphery is estimated to be at a horizontal distance of about 430m from the point A. This position in NS- or EW- cross section is close to either the starting point of a linear stream-fissure inside the newly formed caldera or Hikage-crater (Wada, 1888) on the eastern edge of Numano-taira, respectively. The former is the starting point of massive avalanche toward north and the latter is the breaking open of violent outburst of wind toward southeast along Biwa-sawa.

We conclude that the phreatic pressurized chamber related to the 1888 explosion is not located beneath Kobandai-san (newly formed crater) but just beneath the Numano-taira (ancient crater), from this spot the outbursts were issued to different directions.

Keywords: Bandai volcano, Phreatic explosion, Directed blast, Blast of wind

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SVC047-12 Room:301B Time:May 24 11:30-11:45

The plan imaging the lava dome structure with cosmic-ray muon at Unzen

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It is significant for the growth model of volcano which has viscous magma to investigate the density structure in a lava dome. The project imaging the new lava dome density structure in Unzen, Japan, is going on. The first observation of the imaging a inner density structure in lana dome with cosmic-ray muon was performed by Tanaka et al. (2007) in Showa-shinzan, Japan. The results indicates the growth model advanced by I. Yokoyama in 2002 is most compatible. The lastest lava dome in Mt. Unzen was formed in the eruption from January 1991 to early 1995 and the activity was calmed down in 1995. The formation of the lava dome in Unzen can be divided into two characteristic growth period, exogenous and endogenous. The exogenous dominant period is from January in 1991 to late 1993, the endogenous dominant period is from the end of 1993 to early 1995. Nakada et al (1995) observed that the surface of the lava dome was moving from the in endogenous period in Unzen. They also observed there are several faults, cracks, and th thrusts around the base of lava dome.They proposed a growth model in the endogenous period in Unzen, which is based on their observation and the model includes "peel" structure . According to the dome growth model by Nakada et al, the current density structure in the lava dome should be the following : 1. The ellipsoidal massive part is in the center of lava dome. 2. The talus spread around the massive ellipsoidal. In the talus region, there are a lot of air gaps, which makes the clear contrast in the image of density with muon-radiography. The simulation of the imaging the lava dome with cosmic-ray muon is performed. The parameters are based on the assuption from the peel growth model. As a result, the observation with the muon detector which has 1.0 m^2 as a effective area and with 6 months exposure, the detection of the boundary between ellipsoidal massive part and talus part is possible with 25m spacial resolution. The nuclear emulsion as a muon detector, which has 1.0m^2 effective area, was installed in Unzen in early December 2010. After 6 months exposure and the development of nuclear emulsion, the analysis with automated readout system will start for about two months. We will get the first image in next early autumn.

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Mechanism of foam collapse near the surface: implications for the Vulcanian eruptions

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In the eruption phase of vigorous Vulcanian explosions, lava domes or driblets repeatedly appear in the volcanic crater. It is believed that dense lavas are formed via compaction of melt foam, namely, density contrast between gas and melt matrix causes densification of permeable foam. However, the mechanism of lava formation is still unclear. The permeability of the lavas overlying the melt foam should decrease quickly enough to accumulate magma pressure in the conduit that is required from both geophysical observations and modeling of Vulcanian explosions. In this presentation, we propose that surface tension-driven foam collapse may produce dense andesitic lavas in addition to the compaction driven by gravity.

We have carried out heating experiments of andesitic pumices in the air and evacuated silica glass tubes with NNO buffer. We used the pumice clasts of the 1914 (Taisho) eruption of Sakurajima volcano. Its water content in the groundmass glass is ca. 0.5 wt%. The experimental temperature ranges from 400 to 1000 deg. C, and the run duration from 0.5 to 8 hours. With increasing run duration at 1000 deg. C, the vesicularity decreased in both atmospheric and evacuated runs. At 400 deg. C, however, no significant densification was observed. Since there was no excess confining pressure or shear strain, the only possible force to have caused the densification of melt foam is surface tension of the melt. The textural observations of the bubbles and cavities support this idea. The time scale of compaction and its relation to the interval of Vulcanian explosions will be discussed.

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SVC047-14 Room:301B Time:May 24 12:00-12:15

Brittleness on the fragmentation of vesicular magma

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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 an analogous material of magma.

Silicate magma has viscoelasticity, whose characteristics are approximated using a linear Maxwell model. The Maxwellian viscoelastic material has a relaxation time, which indicates the duration to relax stress in the material. The Deborah number, which is defined as the ratio of the relaxation time to characteristic time of deformation, determines the material behavior as elastic solid or viscous liquid. The porosity of the material, the initial pressure before decompression, and the amount of decompression are also important parameters because pressurized gas in bubbles is the source to induce the fragmentation. According to our latest research, the onset of fragmentation is independent from the initial pressure. Therefore, this experiment can be well explained by using the Deborah number and the differential stress between inner and outer bubble. There is the critical differential stress for causing the fragmentation.

We classify the onset of fragmentation using a new parameter brittleness (Ichihara and Rubin 2010) in the case where Deborah number is in the range from 0.1 to 10. In this case, the viscosity is no longer negligible. Brittleness explains how amount of the total deformation energy is used for the elastic deformation, and is a function of the stress, the rate of change of the stress and the distortional strain. Our purpose is to correlate the onset of fragmentation with the brittleness under various initial conditions. Ichihara and Rubin (2010) have showed that our early experiment (Kameda et al. (2008), the porosity of the material is 0.06 and the initial pressure after decompression is 3MPa) is well explained by the brittleness.

An analogous material of vesicular magma is maltose syrup with oxygen bubbles. The viscosity of syrup depends on the water content and the temperature, while the rigidity is constant. The experiment facility consists of a high-pressure vessel, a large vacuum chamber and double diaphragms. The vessel is decompressed by rupturing the diaphragms. The response of the specimen is observed through window by high-speed photography. Pressure change of vessel is measured by a pressure transducer. The initial high-pressure is set at 1.1 to 3 MPa. Various decompression rates were tested. The specimen had the porosity from 6% to 20% and the viscosity from 105 Pa s to 109 Pa s.

Difference in experimental conditions leads to remarkable change in response of the specimen. We classified the response into three modes: (a) brittle fragmentation without expansion, (b) fracture after small ductile expansion, and (c) ductile expansion without fracture. The mode (a) corresponds to brittle fracture and the mode (b) corresponds to ductile fracture.

The experiment is classified using the brittleness at a bubble surface when the differential stress reaches the critical fracture stress: Mode (a) (the brittleness is from 0.9 to 1.0) occurs regardless of the value of the differential stress; on the other hand, mode (b) (brittleness is from 0.6 to 0.9) occurs only when the excess of differential stress is observed. This means that mode (b) does not occur when the maximum differential stress is close to the critical stress. Finally, mode (c) (brittleness is smaller than 0.6) occurs regardless of the value of the differential stress. This is because that most of the total deformation energy is dissipated due to the viscosity of magma.

We concluded that (1) the fragmentation occurs only when the brittleness is close to unity (magma response is dominated as elastic) if the maximum differential stress is slightly larger than the critical stress; (2) the fragmentation occurs when the brittleness is in the intermediate range if the maximum differential stress is much larger than the critical stress.

Keywords: fragmentation, viscoelasticity, analogous experiment, brittleness

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Self-organized microstructure in flowing suspension

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We present a 3-D numerical simulation developed by combining the discrete element method (DEM) and computational fluid dynamics (CFD), assuming suspensions containing uniform rectangular rigid particles within a Newtonian viscous matrix. Our simulation revealed how the bulk viscosity is determined by the particle orientation, particle concentration, and development of both particle clusters and contact force chains. The evolution of the microstructure is governed by two factors: (1) geometric relationships between the particle orientation and the maximum principal axis and (2) magnitude of particle-fluid and particle-particle interactions, which modifies the rotation behavior of particles. The first factor results in the coupling of the particle orientation and the local fraction of particles. The second factor controls the mean preferred particle orientation and its intensity. Through the combined effect of the two factors, particles are rearranged because of shear-induced strain, and both the microstructure and the bulk viscosity reach a steady-state condition. Under this condition, the microstructure is composed of two domains having different particle fractions and particle orientations. These findings have important implications for the kinematics of the flow-related microstructure recorded in igneous rocks.

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In-situ observation of flowing magma at high temperature and pressure

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The vesiculation and degassing of magma ascending in volcanic conduits control the explosivity and style of volcanic eruptions. To understand these processes, the vesiculation and degassing processes have been simulated by performing decompression and deformation experiments. Previous experiments were carried out using a quench technique in which magma was decompressed and deformed at high temperature and pressure, then cooled to room temperature and atmospheric condition to analyze run products. The quench experiments provided important information for processes whose timescale is relatively long. However, some processes cannot be observed directly. For example, it is difficult to observe brittle fracturing during magma deformation by the quench experiments, which seems to occur during short period and induce efficient degassing through the fractures. In addition, a sequential process of magma vesiculation, degassing, and compaction has not been observed experimentally, although it has been thought to be an origin of effusive eruptions.

In this study, we originally made a deformation apparatus to simulate decompression and shear deformation of magma. This apparatus can be combined with synchrotron radiation X-ray radiography and computed tomography of SPring-8 in Japan. In the apparatus, a sample is placed in a graphite cylinder and sandwiched between two pistons. An upper piston can be rotated by a rotating motor. The sample and graphite cylinder are externally heated using cartridge heaters. A small hole (ca. 10 mm in diameter) is created in the path of X-ray in the apparatus, except for the graphite cylinder which is X-ray-transmissive. To obtain three dimensional image (CT image), the sample is rotated on a theta stage and transmission images are taken from all direction. The approximately 10 degree images cannot be taken in this system because the deformation apparatus has two load frames which support internal pressure in the cell. Thus, the 10 degree images have to be obtained by interpolation. As a preliminary experiment, we performed a torsional deformation experiment at a temperature of ca. 1000 degrees C for vesicular rhyolite. The vesiculation and shear deformation of rhyolite was successfully observed using the X-ray radiography. In future studies, we will perform in-situ observation of shear fracturing and degassing-compaction processes of magma.

Keywords: magma, in-situ observation, shear deformation, vesiculation