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.

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

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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SVC047-15 Room:301B Time:May 24 12:15-12:30

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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SVC047-16 Room:301B Time:May 24 12:30-12:45

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

Japan Geoscience Union Meeting 2011
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SVC047-P01 Room:Convention Hall Time:May 24 14:00-16:30

Across arc variation of Magma Composition in Central Sunda Arc, Indonesia: A test of slab influence to mantle source

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Sunda arc, a part of Pacific ring of fire, extends from West Java to Flores. The arc developed since Tertiary period at a convergent tectonic plate margin, where India-Australian plate is subducted northward beneath Eurasian plate. Central Sunda Arc (CSA) is represented by a series of volcanoes from the fore arc toward the back arc including Merapi, Merbabu, Telomoyo, Ungaran and Muria. The oldest activity represented by Muria was 1.11 Ma (Edwards, 1990) whereas the youngest one by Merapi was October 2010. Depth of Wadati-Benioff zone beneath CSA ranges from 190 km for Merapi (Gertisser & Keller, 2003) to 350 km for Muria (Nicholls & Whitford, 1989). Field works have been conducted for brief geologic observation and rock sample collection from Merbabu, Telomoyo, Muria, including Genuk on the north and Patiayam on the south of Muria. Data from Merapi is compiled from Handini (2010). Rock samples were analyzed using X-Ray Fluorescence, Prompt Gamma Ray and Instrumental Neutron Activation Analysis to obtain whole rock compositions. Using subduction component elements, we tried to estimate the sediment input from the slab in magma genesis of CSA.

High Al_2O_3 (~18 wt%), low Cr (~29 ppm) and Ni (~27 ppm) from CSA products characterize the volcanic products from these volcanoes. K_2O increases gradually with Benioff zone depth. Most samples from Merapi, Merbabu, Telomoyo and Ungaran are classified as subalkaline, whereas Muria samples fail on both Alkaline and Subalkaline fields. In detail, Merapi samples range from Medium-K to High-K, Merbabu Medium-K, Telomoyo and Ungaran High-K, and Muria samples range from High-K to Shosonitic and Leucitic. We only selected unfractionated lavas to avoid assimilation, including basalt, basaltic andesite, andesite, basanite, trachy basaltic andesite and trachyandesite.

Chondrite normalized REE pattern of Muria samples including Genuk and Patiayam shows steeper patterns than those from fore arc volcano. LREE to HREE ratios of Muria samples are up to four times higher than those from the frontal volcanoes. Lead to HFSE ratios (e.g. Pb/Nb) reach the highest point around Merbabu (~17) and Telomoyo (~21) instead of frontal Merapi (~14), and gradually decrease toward back arc, suggesting the strongest sediment input at Merbabu and Telomoyo. Lead to HFSE ratios are the lowest (~0.25) at Muria Leucitic products. Those of Muria shoshonitie are ~0.67, and those of Muria High-K are ~1.27. Boron to HFSE ratios which also indicate the fluid significance on magmatism shows similar pattern with Lead. These results from fluid mobile elements provide possibilities on estimating slab influence to mantle source in CSA.

Keywords: Subduction, Across sunda arc, Quartenary volcanism, Fluid mobile element

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SVC047-P02 Room:Convention Hall Time:May 24 14:00-16:30

Quartenary Gede Salak volcanic complex, Banten area, at the junction between Sumatra arc and Java arc, Indonesia

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Pleistocene Gede Salak volcanic complex is located at Banten, northwestern edge of Java island. The volcanism is associated with the subduction of the India-Australia plate beneath Eurasian plate at the rate of 7 cm/y. These volcanoes are located near Sunda Strait, a transitional zone between Java arc and Sumatera arc where oblique subduction is observed. The distance from Java trench is 300 km, with a diameter of 30 km. This volcanic complex consists of Gede, Salak, Batur and Wadas volcanoes. To southeast is located Pinang volcano, and to south is Volcanic complex of Rawa Dano. This study is the first geochemical study of volcanic rocks characterizing across-arc variation of Java-Sumatra junction.

Gede Salak volcanic complex consists of pyroclastic flow deposits in the western part and lava flows in the eastern part. The later development of dome Wadas formation is probably associated with fault structures trending northwest to southeast.

Volcanic samples from this volcanic complex include basaltic to trachytic rocks, in the range of medium-K to high-K MgO content is less than 3 %. Elements of Rb, Zr, Ce, and La increase with increasing SiO2. Chondrite-normalized REE patterns are similar to those of island arc basalts. When compared to volcanic samples from central western Java volcanoes, REE pattern is similar to those from backarc volcanoes (Sendjaja et al. 2009). Gede Salak volcano is slightly enriched in the subduction component, as illustrated by the low Nb/Zr and elevated Ba/Zr ratios. B/Nb and B/Zr ratios are in the range of (1.5 - 5.4) and (0.03 - 0.10), which are higher than the back arc volcano in central Java transect, but lower than the frontal volcanoes there.

Keywords: basalt, subduction, Gede Salak volcanic complex, Northwestern Java

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SVC047-P03 Room:Convention Hall Time:May 24 14:00-16:30

The transition of eruptive style and crystallization process in the 1914-1915 eruption of Sakurajima volcano

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We investigated the 1914-1915 eruption of Sakurajima volcano as a test case of the eruptive style transition, because the factor of such a transition in a single sequence of eruption hasn't been elucidated yet. In this eruption, explosive eruption produced a large amount of pumices in the early stage, and subsequently the lava flew out by non-explosive eruptions after the middle stage.

To get the clue of factors controlling the transition of eruptive style, in this paper, we examine the crystallization process of plagioclase microlites and phenocrysts in pumice and lava. Microlite is a minute crystal smaller than 100 micrometer in length, crystallizes in the conduit. Microlites crystallize when the ascending magma in the conduit experiences decompression and vesiculation and H_2O exsolution occurs. H_2O exsolution increases the liquidus temperature of the magma and leads to the supercooling state of the magma.

We sampled the pumices and lavas erupted by Sakurajima Taisho eruptions in order to examine the difference of the eruptive style. Sakurajima Taisho pumice is classified into white pumice(major) and gray pumice(minor), both of which we analyzed. Sakurajima Taisho lava is classified into 16 units in the order of flow. We analyzed 8 units of them. To discuss the behavior of magma just before it flew out of the conduit, I analyzed the composition of plagioclase microlites and rims of plagioclase phenocrysts using FE-EPMA. We measured plagioclase microlite crystals size distribution using image processing software "ImageJ".

The results are, An content of microlite is about 45-55 mol%, in contrast, that of phenocryst rim is about 50-65 mol%. There is no difference in chemical composition of plagioclase microlite between lava and pumice. Regarding CSD, the plagioclase microlites are dominated in sizes smaller than 10 micrometer in lavas, whereas they are 10-20 micrometer in pumice. Plagioclase microlite number density of lava is considerably larger than that of pumice.

It is considered that the magma composition or physical condition when microlite crystallized is certainly different from one when phenocryst rims grew. The difference of eruptive style influences rather both the crystallinity and number density of plagioclase microlite than the chemical composition of plagioclase microlite.

Keywords: Sakurajima, microlite, eruptive style, chemical composition, pumice, lava

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SVC047-P04 Room:Convention Hall Time:May 24 14:00-16:30

Prior processes of Vulcanian eruption at Showa crater of Sakurajima volcano

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From our multi-parametric observations carried out at Sakurajima volcano, typical prior processes of a Vulcanian eruption have been revealed as follows. At a few hours before the eruption onset, magma starts to migrate and storage in shallow depth, which is recognized in record of strain change as an inflation process. Since a few tens minutes before the eruption, SO_2-gas discharge rate is gradually decreasing. This indicates that a sealing process at the crater bottom toward the eruption progresses. In the time of around 10-20 minutes before the eruption, inflating rate of the volcano starts to increase due to a construction of a plug above the conduit thus a formation of a gas pocket beneath the carter. At a few minutes before the eruption, small tremor starts to emerge and then its amplitude becomes larger with strain changes of inflation turning to be deflating and minor discharge of a hot gas as the pressure release through fractures newly constructed within the plug. Seismograms show that expansion process starts to occur at only one second before the eruption. It is probably the time when effect of the depressurization process reaches to the depth of dense magma head and sudden expansion of magma with degassing starts. About a half of a second later, such expanding magma rises and pushes the gas pocket up. It leads to swelling of crater ground and its failure. Consequently, the accumulated gasses and expanding magma itself ejects together from the crater as a start of eruptive surface phenomena.

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SVC047-P05 Room:Convention Hall Time:May 24 14:00-16:30

Magma plumbing system and ground deformation associated with the eruption at the Showa crater of Sakurajima in 2009

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Many qualitative studies have been conducted on the mechanism of a volcanic eruption from the analyses of volcanic ejecta and from geological interpretations. However, little is known about the quantitative evaluation of the mechanism in terms of magmatic flow. There are indeed some quantitative studies about the part of an eruptive system such as a volcanic flow, a crystallization differentiation in a magma reservoir etc., but very few to consider the system consisting of a magma reservoir and a volcanic conduit together.

Here, we studied the magma plumbing system inferred from the ground deformation associated with the eruption at the Showa crater of Sakurajima volcano. After the application of the Mogi's model to data in the past geodetic observations, the existence of two magma reservoirs has been inferred beneath the summit of volcano at depths of 4 km and 0.1 km, respectively. The change in the tilt and strain data in two underground tunnel sites observed 36 hours before an eruption in April 9, 2007, are analysed in terms of the behaviour of magma prior to the eruption. An about three-hours time lag in the inflation and the difference in the volumetric change were observed between the two reservoirs. We conducted a numerical simulation to investigate the magma plumbing system and to explain the time-lag in the inflation between the two reservoirs. Our model consists of shallow and deep magma reservoirs interconnected by a vertical conduit through which gas-liquid two-phase magma flows with phase change. Two conditions of a constant magma supply into the deeper and of a pressure threshold to initiate the ascent of magma to the shallower are given to the model. We confirmed that our hypothetical model could explain the time lag of the inflation. As a next step, we would like to describe the difference in the volumetric changes using our model.

Keywords: eruption, volcanic conduit, magma reservoir, sakurajima, ground deformation, numerical simulation

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SVC047-P06 Room:Convention Hall Time:May 24 14:00-16:30

Monotonic infrasound at Volcan Villarrica, Chile

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Volcan Villarrica in the southern Andes, Chile, is an active stratovolcano that hosts a convecting lava lake in the summit crater. The Villarrica lava lake is typically overhung by spatter roof that is broken by a central skylight through which the lava lake can be glimpsed. In January 2010 we pointed a video camera at the open vent and coincidentally recorded infrasound to better understand sound generation. We observed monotonic infrasound with stable peaked frequency of 0.77 Hz although there was a lack of visual correlation between discrete explosions and infrasound production. We demonstrate that the likely source of infrasound is Helmholtz resonance produced from a cavity that separates the active convecting lava lake from an overhanging spatter roof.

When pressure perturbation is applied to an air plug in a constriction (e.g., neck of a bottle or vent skylight) that is connected to a cavity, the plug will oscillate (Helmholtz resonance). The idealized Helmholtz frequency is given by:

$f=(c/2*3.14)*(S/VL)^{1/2}$ (1)

where c is sound velocity in the cavity, S is neck cross sectional area, L is neck length and V is cavity volume. In practice, an extra air volume proportional to the neck radius moves together with the air above and below the neck. This end effect may be added to the geometrical length of the neck and is calculated as 0.85 times the radius for a flanged end and 0.61 times radius at non-flanged (pipe) end (e.g., Fletcher and Rossing [1998]). By considering the skylight as a circular flanged hole with radius r, and when skylight length is negligibly short, Helmholtz resonance frequency is given by:

$f=(c/2*3.14)*(3.14*r/1.7V)^{1/2}$ (2)

Assuming Villarrica volcanic gas concentrations is 95 mol% H_2O, 2.0 mol% CO_2, 2.1 mol% SO_2, and less than 1 mol% of other species [Shinohara and Witter, 2005] and using mixing theory for each gas species [Morrissey and Chouet, 2001], c=514 m/s assuming cavity temperature is 200 ^{o}C. Using this value with f = 0.77 Hz and r = 5 m (skylight radius determined from video imagery) we obtain a cavity volume of $1.04*10^5$ m^3 from eq. (2), and the cavity height is 31 m if we adopt cylindrical shape with the same diameter as that of spatter roof (65 m).Cavity gas might also mix with ambient atmosphere whose velocity is 0.85 times lower than that of Villarrica volcanic gas for the same temperatures. Although the atmosphere-volcanic gas mixing ratio in cavity is unknown, eq. (2) would predict a volume and height estimations as low as $7.51*10^4$ m^3 and 23 m, respectively, for a cavity filled with atmospheric air at 200 ^{o}C. The actual cavity height should then most probably be somewhere between 23 m and 31 m.

In the video we are able to identify occasional lava dripping from the edge of skylight and falling into the lava lake. Forty-four independent measurements of fall time range from 1.3 to 2.2 sec with a 1.76 s average, corresponding to free fall distances between 8 and 24 m with an average of 15.5 m if we ignore drag force of the atmosphere. The wide range in estimates could be by dynamic levels of the lava surface due to bubble slug arrival and surface disruption and poor visibility due to volcanic fume that serves to decrease the estimated fall times. For these reasons we propose that the actual cavity depth could correspond to a fall of at least 2.2 s (or 24 m). The 24 m dimension is similar to the 23-31 m estimate determined from the Helmholtz resonance model, showing the plausibility of Helmholtz resonance for observed monotonic infrasound at Villarrica.

Keywords: Infrasound, lava lake, Helmholtz resonance

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SVC047-P07 Room:Convention Hall Time:May 24 14:00-16:30

Vesicle nucleation, growth and coalescence processes in felsic magma, inferred from textural change in a volcanic bomb

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For further understanding of vesiculation and gas separation processes in felsic magma, we analyzed vesicle textures of a volcanic bomb from a vulcanian eruption of Asama volcano in 2004. Rim to core textural analysis of a bomb should provide knowledge of textural evolution, as the time from the vulcanian explosion to the magma solidification at the surface should have increased toward the core of the bomb.

The radius of the bomb is about 10cm. Regardless of the position in the bomb, the phenocryst and groundmass microlite contents are homogeneous (40vol.% as whole rock, and 20-30 vol.% in groundmass, respectively). The bomb has step-like textural change, characterized by dense, dark gray chilled margin (ca. 1cm width) and light gray, vesiculated inner part. For the thin section making and quantification of the texture, we chose 6 parts (ca.0.2cm, 1cm, 2cm, 3.5cm, 6, cm 8.5cm from the outermost rim) in a section cutting the center of the bomb. Part1, Part2 and Parts 3-6 correspond to chilled margin, boundary between chilled margin and inner part, and inner part, respectively.

Part1 is vesicle-free, while Part2 shows gradual increase in vesicularity. Parts3-6 have constant vesicularity (64-67% in groundmass part) regardless of the distance from the outermost rim. Part2 includes up to 50 micro meter vesicles having circular shape. Parts1-2 probably record vesicle nucleation and growth processes which took place in conduit and in air after the vulcanian explosion. Vesicle-free and vesicle-abundant parts coexist in Part 2, which may provide keys to understand the vesicle nucleation processes.

Although Parts3-6 show constant vesicularity, they show systematic change in vesicle size distribution and number density with the distance from the outermost rim. Volume ratio of vesicles with less than 500 micro meter length shows decrease toward the core; ca. 90% in Part3 and ca. 75% in Part6. Number density of the vesicles with the same size rage is lower in Parts 5-6 ($6.7\text{-}6.2*10^4/mm^3$) than in Parts 3-4 ($11.0\text{-}7.8*10^4/mm^3$). On the other hand, vesicles up to 1cm length, seen in naked eyes, are limited to Parts 5-6. In Parts 3-6, vesicles mostly have irregular shape and vesicles of circular shape are mostly connected one another. These findings in Parts 3-6 may indicate evolution of bubble coalescence toward the core of the bomb. Also, the shape relaxation of the coalescenced vesicles may have progressed with the delay of the solidification, as evidenced by the higher circularity of the vesicles in Parts5-6 than in Parts3-4.

Keywords: volcanic bomb, felsic magma, vesicle nucleation, vesicle coalescence, vesicularity, vesicle size distribution

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SVC047-P08 Room:Convention Hall Time:May 24 14:00-16:30

Analogue experiments on degassing from deformable bubbly fluid by decompression

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Bubbles in magma affect eruption styles, since rapid expansion of bubbles in magma causes explosive eruptions. If volcanic gas in bubbles escapes quietly to atmosphere (which is a process called as degassing), an explosion may be suppressed. Degassing is thus an important process in conduit, but its details have not yet been well understood. Since it is difficult to observe bubbly magmas inside a conduit directly, we here perform an analogous experiment.

We simulate the magma ascending in a conduit by vacuuming a tank with internal dimensions of 900 x 600 x 40 mm^3 in which bubbly fluid is enclosed. For our magma analogue, we use three kinds of syrup whose viscosities are 10, 1000, and 4000 Pa s which cover the viscosity ranges of basaltic to low viscosity andesitic magmas. Bubbles in syrup are created by chemical reactions. The decompression rate depends on the sealing of the experimental tank. We measured the pressure inside and outside the bubbly syrup by pressure transducers attached to the bottom and top of the experimental tank, respectively. We can calculate the pressure gradient inside the bubbly syrup by these two measurements.

In experiments, we find that bubbles expand through decompression and the bubble films finally break such that bubbles become interconnected. The gas inside bubbles escapes from the surface of the bubbly syrup. Observed volume of bubbles in the syrup (V_a) is significantly smaller than the estimated one assuming that bubbles initially included in the syrup expands without degassing (V_i), indicating the occurrence of degassing. Degassing begins when volume fraction of bubbles reaches at around 0.8~0.9. We calculate degassing rates by using values of V_a and V_i ,and find correlations with pressure gradient within the bubbly syrup suggesting that pressure gradient drives degassing. Although the shape of the interconnected bubbles is subject to deformation and the apertures on bubble film may close eventually, degassing observed in our experiments apparently follows classical Darcy's law. We estimate permeability and obtain values 10^{-7}~10^{-10} m^2. These are larger than those measured with solidified magmas. We also find that permeability for less viscous syrup is larger than that for more viscous syrup. In our experiments, pressure differences between inside and outside the bubbly syrup becomes larger for more viscous syrup and higher decompression rates. We infer that bubbles are unable to expand sufficiently fast to allow the pressure inside bubbles to equilibrate with the pressure outside bubbles as it has been suggested.

We thus conclude that deformable magma could be degassed more efficiently than that it has been estimated and degassing becomes more efficient for less viscous magma with higher decompression rate.

Keywords: volcano, eruption, degassing, bubble, analogue experiment, conduit

SVC047-P09 Room:Convention Hall Time:May 24 14:00-16:30

Effects of rising velocity of magma changing its intruded shape

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We employed software PFC 2D (Particle Flow Code in 2 Dimensions) based on discrete element method and studied effects of which rising velocity of magma would control shape of intruded magma. Although behaviors and shapes of the intruded magma would be controlled by various factors, here we paid attention to the rising velocity of intruding magma because the velocity would reflect directly overpressure from deeper magma chamber.

In the discrete element method, all materials are approximated by assembling of many particles, and one particle and other particles are connected by elastic 2 springs (normal and shear stiffness). If necessary, we can set parameters, bond, for connecting particles. By trial and error, these parameters are determined by biaxial test in a computer. In this study, we assumed Young's modulus of 16 GPa and Poisson's ratio of 0.21 as elastic constants of basaltic crust near the surface, and we estimated the normal and shear stiffness of 50 GN/m and the normal and shear contact bonds of 3 kN, to satisfy the mentioned elastic constants, by the biaxial test. The normal and shear contact bonds of intruded magma were set to 0 kN for keeping fluidity.

In this study, we considered the model of which width and depth are 5 km and 1.6 km. We assumed that the intrusions of magma would be pushed out from bottom of the model by an arbitrary rising velocity, and we evaluated effects of the rising velocity changing shape of the intruded magma. In the model, radius and density of particles constituting the crust were assumed to be 4.8~6.4 m and 2500 kg/m^3, and radius and density of particles constituting the magma were assumed to be 0.8~0.96 m and 2000 kg/m^3. The final volume of the intruded magma was set to 2e^5 m^3 in all simulations, and we changed the rising velocity from 5e^{-4} m/step to 0.16 m/step.

As a result, it was found that the shape of the intruded magma was circular in an initial stage of intrusion and that they were irrelevant to the rising velocity. However, the final shapes were dependent on the rising velocity. If the velocity was slow, the intruded magma grew up as the elliptical shape elongating upward. On the other hand, if the velocity was fast, the intruded magma grew up as the circular shape of which lower parts were elongated sideways or the triangle shape with blunt corner. In addition, the slow rising velocity deformed widely the surface, because the magma having slow velocity grew up more upward than the magma having fast velocity.

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A thought experiment on the volcanic eruption by means of the shock-wave fracturing pipe model

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The above-mentioned model was proposed as an ore-forming model for the unconformity-related uranium deposits in the Proterozoic continental basin such as the Athabasca basin, Canada (Iida, 2008; Society of Resource Geology the 58th Annual Meeting, P-32). The scenario is as follows. (1) A buried monadnock at the basin bottom exists as a low-pressure pod owing to the overlying sandstone dome roof that supports the load. (2) The roof is crushed by increasing load pressure with deeper burial. Two shock waves are discharged into the opposite directions of the subhorizontal major axis of the pod. (3) The shock wave tends to concentrate on the center instead of diffusing because the intense fracturing slows the wave speed. As the result the fracturing pipe is formed in the track of the shock wave. (4) A shock wave directed to the updip side is refracted upward due to slower wave speed in the upper levels. The other shock wave to the downdip side gradually attenuates into a normal push wave without fracturing. (5) The created pipe hydraulically connects the basin bottom with the surface level, and makes a long term circulation of ground water (ca. 400 million years), that forms the ore deposit (the later process is omitted).

In general any pipe structure is formed by the shock wave discharged with the crush of the low pressure pod. For example the breccia pipes in the Grand Canyon area seem to be formed by the shock waves discharged with the crush of buried limestone caves (they are normally explained with collapsing above the cave). Also the large vertical holes on the Guiana Highlands may be formed by the same process.

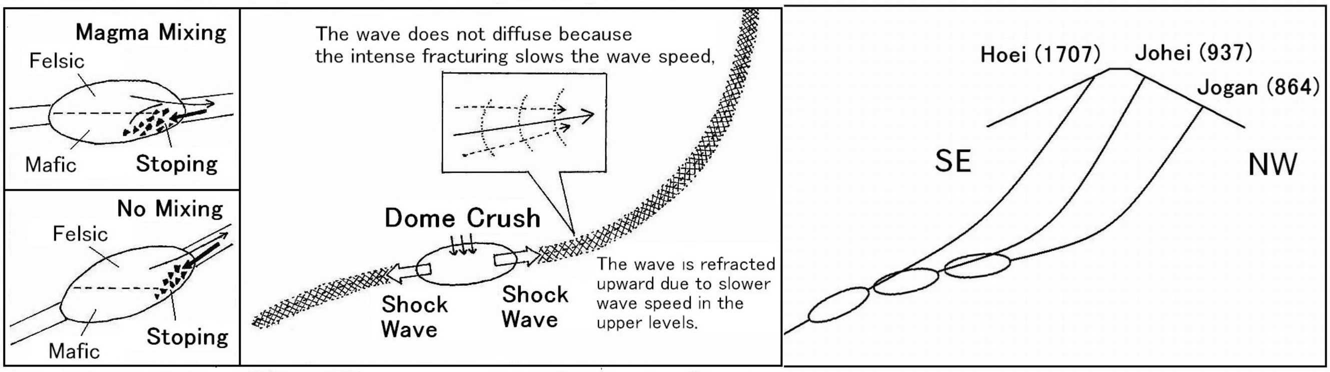
I propose to apply the model to the formation of the volcanic vent. The established theory explains that the eruption happens by pressure rise caused by boiling in the magma reservoir. The boiling, however, should stop when the pressure rises under the closed condition, and the explosive pressure rise can not be expected. The explosive boiling happens under the open condition that is on the way of the vent. In addition, if the eruption is due to the pressure rise, then the tension cracks could be formed above the reservoir, but the pipe shaped vent can not be formed.

The magma reservoir is supported by the dome roof in the course of lowering the magma pressure with the volume loss due to the crystallization. The vent forming process with the crush of the low-pressure pod is same as the above-mentioned ore-forming process. The rock fragments in the fracturing pipe on the up-dip side flow into the reservoir gravitationally (same as the stoping of mining). In place of the rock flow the magma rises in the pipe. If the magma is differentiated into the felsic and mafic magmas, and the reservoir is flat shaped, then the magma mixing occurs with the stoping. In the case of inclined reservoir, the mixing does not occur; but firstly the overlying felsic magma spouts out in order that is followed by the mafic magma (the Hoei eruption of the Mt. Fuji in 1707 is regarded as this case). The rising magma boils on the way, and erupts explosively. In case of the viscous magma, it takes time to rise, and the secondary reservoir may be formed, that may eject the pyroclastic flow.

After the eruption, the magma should step back to the pipe of the downdip side gradually. The next eruption should move to that direction. As the result of the repeated magma migration, the craters should line up. A linier distribution of the craters is commonly regarded as a tectonic line control, but it is not the case; the major axis of the reservoir is reflected on the lineup.

If the proposed model is correct, the eruption should be able to be induced by blasting the dome top. I expect that the induced eruption prior to the occurrence of dangerous eruption will come true in the future. Similarly I would like to expect the progress of the research into the induced earth quake.

P.S. the eruption of the Mt. Shinmoe-dake will be discussed.



Keywords: shock wave, pipe structure, volcanic eruption, stoping, magma mixing