Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-01 Room:315 Time:May 2 09:00-09:15

The mathematical link between stratigraphic grain size variation of fall deposits and its time variation at the source

IRIYAMA, Yu[1*] ; TORAMARU, Atsushi[2] ; YAMAMOTO, Tetsuo[3]

[1]Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, [2]Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, [3]Center for Planetary Science, Kobe University

Pyroclastic fall deposits which are produced by explosive volcanic eruption have various information on the eruption events. The areal distributions of pyroclastic fall deposits such as maximum grain size, median grain size, thickness, mass per unit area, etc. reflect the intensity in a single eruption and the wind conditions. Stratigraphic grain size variations of pyroclastic fall deposits also reflect the temporal behavior of the eruption intensity. For example, normal or reverse grading structures in the pyroclastic fall deposits have been attributed to temporal variation in the volcanic intensity (column height) and/or in the initial grain size distribution at the vent. However, no quantitative methodology has been developed to relate the temporal variation of source characteristics (column height and initial grain size distribution) to stratigraphic variation of grain size distribution at the deposits. In this study, we consider the mathematical description in 1D fall-sedimentation process, which relates the temporal variation of source grain size distribution to stratigraphic variation of grain size distribution.

The number of grains in a size bin must be conserved during sedimentation process and results in the same value at the arrival time on the deposits. The number of a specific-size grains between at the fallout time and at given times is linked by Lagrangian description. The key point is that the grain size and the departure time at the source are mutually related to the grain size and the arrival time at the deposits. As the arrival time corresponds to the stratigraphic location at the deposit, the stratigraphic variation of grain size in the deposit can be connected to the grain size characteristics and departure time at the source using the condition of grain number conservation. As a result, when the time variations of source grain size distribution and of fallout height are given, we obtain the temporal variation of grain size distribution at the sedimentation surface. It means that different sizes of grains which settle at the same arrival time are traced back to the different source time and height. The arrival time on the deposit can be related to the stratigraphic height in the deposit by the differential equation of increasing rate of the thickness, which equals to the volume flux through the sedimentation surface. By using these mathematical descriptions, we develop the mathematical method to link the temporal variation of eruption intensity to the stratigraphic variation of grain size distribution in the fall deposits.

Keywords: pyroclastic fall deposits, grain size distribution, stratigraphic variation, development of eruption

SVC50-02 Room:315 Time:May 2 09:15-09:30

Color and grainsize of ash samples collected continuously at Sakurajima volcano, Japan

SHIMANO, Taketo[1*] ; NISHIMURA, Takeshi[2] ; IGUCHI, Masato[3] ; MIKI, Daisuke[3]

[1]Graduate school of Enviroment and Disaster Research, Tokoha University, [2]Department of Geophysics, Graduate School of Science, Tohoku University, [3]Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

Sakurajima volcano, Southwest Japan, is one of the most active volcano, and one of the leading volcano that are characterized by well-established geophysical observation network and enormous amount of data accumulation. Thus, the changes of magma plumbing system and the explosion processes at Sakurajima are now relatively well-understood for the time scale of years and of several hours, respectively (Iguchi et al., 2013). On the other hand, Sakurajima volcano has experienced several giant explosive eruptions every few hundred years, with some plinian eruptions and with erupted volume in the order of $>10^8$ m^3. However, we do not understand the mechanism of phase transition from the recent small eruptions to such bigger ones. Even though we now reached a certain level to recognize that our knowledge of " vulcanian eruption " was too simple relative to real one, the fundamental processes that lead to such eruption variety are not yet constrained well enough. As the variety of eruption styles occurs in a time scale of months to days, we have been focusing on the sample acquisition in this time range and collected daily ash samples for years.

We have been succeeded in collecting daily samples by automatic sampling system for more than five years at the site ca 2 km south of Showa crater, Sakurajima volcano (Shimano et al., 2013). We also analyzed matrix glass composition to track chemical evolution of the magma system, and found a shift of FeO^*/MgO in fall of 2009 before the waxing activity toward 2010. On the other hand, we have been searching for some real-time technique of petrological data for the comparison with geophysical data. The development of useful colorimeter and some results of heating experiments of ash resulted in understanding relationship between color of ash and condition of magma at depths (e.g., Yamanoi et al., 2008; Miyagi et al., 2013). So we have made time-series color measurements of ash samples for years. We found L^* value, degree of brightness, decreased broadly during waxing stage in 2009-2010 whereas a^* and b^* values increased broadly at first several months but decrease gradually. These changes can be explained by increase of black fresh lava block particles, increase at the first stage and gradual fluctuating changes of old red oxidized particles in ash sample. We also measured color change of some grain size group and compared with the color of bulk samples. The preliminary results show that the color differs with particle size as Miyagi et al. (2010) reported, but a correlation was found between the color values of bulk sample and those calculated from the weight fraction and each color values.

Keywords: volcanic ash, continuous observation, color change, Sakurajima volcano

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-03 Room:315 Time:May 2 09:30-09:45

Numerical Simulation of Volcanic Ash Transport for the Eruptions at Mt. Shinmoe-dake during 26-27 January 2011

HASHIMOTO, Akihiro[1*] ; SUZUKI, Yujiro[2] ; SHIMBORI, Toshiki[1] ; TAKAGI, Akimichi[1]

[1]Meteorological Research Institute, Japan Meteorological Agency, [2]Earthquake Research Institute, The University of Tokyo

The volcanic ash transport associated with the eruptions at Mt. Shinmoe-dake during 26 to 27 January 2011 is simulated using Japan Meteorological Agency Non-Hydrostatic Model (JMA-NHM) to verify the model with satellite observation. In the model, the mixing ratio and number concentration of ash particles are prognosed with the advection, diffusion, sedimentation, and source terms to represent the behavior of ash cloud. Simulation has been performed in the calculation domain covering 2500 km x 2000 km wide area with the horizontal resolution of 5 km.

The model is coupled with one-dimensional eruption column model to define the source term of ash particles, which is simply given as a function of the column height, the level of the release point, and the size of released particle, following Suzuki (1983) and Shimbori et al. (2010). Although the simulated distribution of ash cloud roughly agrees with satellite observation, close examination of the simulation result shows that the model fails to reproduce some of the ash clouds observed by the satellite, which means that much room still remains for improvement in the eruption column model in terms of release point and size spectra of ash particles. Three-dimensional direct numerical simulation has been conducted on a major sub-Plinian eruption during the period at Mt. Shinmoe-dake (Suzuki and Koyaguchi, 2013), in order to make new eruption column model with more realistic function for the source term of ash particles. As a result, it is found that the maximum release rate of the ash particles smaller than 100 μm appears in the height lower than that predicted by the usual eruption column model for same column top height. The authors are developing new eruption column model with realistic profile of release rate, based on this result, so as to improve the reproducibility of the ash transport with JMA-NHM. The sensitivity of the ash transport to altering the new and usual eruption column models will be presented.

Acknowledgement
This study was supported by the Earthquake Research Institute cooperative research program.

References
Shimbori, T., Y. Aikawa, K. Fukui, A. Hashimoto, N. Seino, and H. Yamasato, 2010: Quantitative tephra fall prediction with the JMA mesoscale tracer transport model for volcanic ash: A case study of the eruption at Asama volcano in 2009. *Pap. Met. Geophys.*, **61**, 13-29.
Suzuki, T., 1983: A theoretical model for dispersion of tephra. *Arc Volcanism: Physics and Tectonics. TERRAPUB*, 95-113.
Suzuki, Y. and T. Koyaguchi, 2013: 3D numerical simulation of volcanic eruption clouds during the 2011 Shinmoe-dake eruptions. *Earth Planets Space*, **65**, 581-589.

Keywords: volcanic-ash dispersal, Atmospheric Transport Model,, Shinmoe-dake volcano, 2011

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-04 Room:315 Time:May 2 09:45-10:00

Weather Radar Investigation of Volcanic Smoke for Disaster-Prevention

MAKI, Masayuki[1*] ; IGUCHI, Masato[2] ; FUJITA, Eisuke[3] ; MAESAKA, Takeshi[3] ; SHUSSE, Yukari[4] ; KOZONO, Tomofumi[4] ; MOMOTANI, Tatsuya[5] ; YAMAJI, Akihiko[5]

[1]Kagoshima University, [2]DPRI, Kyoto Univercity., [3]NIED, [4]Tohoku University, [5]Japan Weather Association

Sakurajima volcano has been active since February 2009. The total number of explosive eruptions was 966 in 2011, which was the highest number in recorded history. Corresponding to volcano activities, the ash accumulation in Kagoshima city increased and total ash amount of 3,500g/ m2 was recorded at Kagoshima local meteorological observatory. Because the volume of volcanic ash in rural area paralyze public ground transportations such as rail road and highway, fast recovery efforts are required to the railroad company and city government. However, no quantitative volcanic ash fall estimation has been established. The present study focuses on utilization of operational weather radar for quantitative ash estimation (QAE), quantitative ash forecasting (QAF), and utilization of crustal movement information for providing ash volume which is necessary for initial conditions of a numerical diffusion model. Although the target volcano of the present study is Sakurajima, the knowledge on volcanic ash and algorithm developed by the present study can be applied to any other volcano which is located in operational weather radar observation area.

Keywords: weather radar, volcanic ash, quantitative ash estimation, Sakurajima, polarimetric radar

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-05 Room:315 Time:May 2 10:00-10:15

Eruption types determined by the mass flux and volatile component content of ascending magma flow

IDA, Yoshiaki[1*] ; OIKAWA, Jun[2]

[1]Advance Soft Co., [2]Earthquake Res. Inst., Univ. of Tokyo

Volcanic eruptions include the effusive ones that erupt fluid lava and the explosive ones that emit magma fragments in gassy flows or other forms. Traditionally, explosive eruptions are further classified into Plinian eruptions accompanied by high eruption columns, Pelean eruptions involving abundant pyroclastic flows, Vulcanian eruptions with strong instantaneous explosions, Strombolian eruptions involving periodic lava fountains and so on. Effusive and explosive eruptions are clearly controlled by the efficiency of degassing, but what produces various types of explosive eruptions has not yet been explained quite clearly. In this paper I propose a simple idea about how various explosive eruptions arise depending on the natures of ascending deep magma flow based on a stationary conduit flow model.

The state of erupting magma may be represented by exit velocity and the volatile content that determines the vesicularity of volcanic products. The volatile content is specified by its mass ratio to the fluid magma (including solidified part). On the other hand, it is convenient to represent the deep state of magma flow by the mass flux of fluid magma and the volatile contents before degassing takes place. When the magma flow is in a stationary state the mass flux of fluid magma is constant so that it defines the deep state of magma flow with the initial volatile content independently of the specific depth at which magma ascent starts.

The relation between the surface and deep states of ascending magma is calculated using a stationary conduit flow model. In this calculation the volatile component is assumed to move at the same speed as the fluid magma neglecting relative motions. In bubbly magma horizontal permeable flow of volatile gas is assumed to control the rate of degassing. In this treatment, the pressure gradient that drives the permeable flow is considered to arise from the ascent velocity change from center to side and the resulting difference of relaxation of gas expansion due to decompression (Ida, JVGR, 162, 172-184, 2007). The wall friction is assumed to be proportional to ascent velocity in bubbly flow and to the square of ascent velocity in gassy flow with suitable friction coefficients. The relation for water steam in magma is used for solubility of volatiles in magma.

The integration of conduit flow is executed from the surface to a deep conduit. Namely, the deep state of magma flux and volatile content are calculated for various sets of the exit velocity and volatile content at the surface prescribed with the magma pressure equal to the atmospheric pressure. Compiling the calculation results shows that some groups characterize the relation between the surface and deep conditions. Each group can be interpreted in connection with eruption types in the following way.

Firstly, high-speed gassy flow erupts violently when the deep magma contains sufficiently abundant volatile component. This case may produce a Plinian eruption. In this case the exit velocity and gas content are determined by the deep magma flux alone independently of deep gas content because of adjustment by degassing during the ascent process. Secondly, a stationary conduit flow disappears below the critical value of fluid magma flux with high gas content in a deep conduit. In this case magma flow should be non-stationary and may produce Vulcanian or Strombolian eruptions. Thirdly, a relatively slow magma flow with low vesicularity flows out when volatile component is poor. This case likely results in Pelean eruptions because of difficult acceleration of gassy flow in the air.

Our analysis and interpretation suggest that various eruption types arise from different combinations of ascending magma flux and degassing efficiency. It is non-linearity involved in ascending magma flow with vesiculation and degassing that produces separate groups characterizing eruption types.

Keywords: volcanic eruption type, ascending magma flow, conduit flow model, volatile component content, degassing, computer simulation

SVC50-06 Room:315 Time:May 2 10:15-10:30

Magma eruption rates, eruption styles, and preeruptive magma viscosity

TOMIYA, Akihiko[1*] ; KOYAGUCHI, Takehiro[2] ; KOZONO, Tomofumi[3] ; TAKEUCHI, Shingo[4]

[1]Geological Survey of Japan, AIST, [2]Earthquake Research Institute, University of Tokyo, [3]Department of Geophysics, Graduate School of Science, Tohoku University, [4]Civil Engineering Research Laboratory, Central Research Institute of Electric Power Industry

Magma eruption rate is one of the most fundamental parameters for a volcanic eruption (e.g., Pyle, 2000). It is obtained mainly by geophysical or geological observations. We interpret this important parameter from a petrological point of view and also from a fluid dynamic point of view.

We have collected a hundred of data on magma eruption rates, bulk rock chemical compositions, and phenocryst contents for various styles of eruptions (Plinian, sub-Plinian, basaltic Plinian, lava flow, and lava dome). We are compiling these data on the basis of their 'preeruptive magma viscosities', which are important measures of magma eruptibility (Takeuchi, 2011). Preeruptive magma viscosity is the viscosity of magma (melt + crystals) in the magma chamber at the preeruptive conditions. This value can be obtained by the bulk rock chemical composition and phenocryst content, using an empirical formula (Takeuchi, 2010). We have found that eruption styles are closely correlated to preeruptive magma viscosities but poorly correlated to bulk rock compositions.

We have also examined the difference in magma eruption rates between the explosive phase(s) (e.g., Plinian) and the effusive phase (e.g., dome) in a series of eruptions, in order to understand the transition between these two eruption styles (e.g., Kozono and Koyaguchi, 2009a,b). We have found that the difference is positively correlated to preeruptive magma viscosity.

The above results indicate that preeruptive magma viscosities largely control eruption styles and eruption rates. Our results also show that the eruptive magmas are divided into two types, low-viscosity type (basalt to low-phenocryst-content andesite) and high-viscosity type (high-phenocryst-content andesite to rhyolite). The boundary is at about 10^4 Pa s. These two types may be closely linked to the magma generation processes (e.g., fractional crystallization and melt segregation from crystal mush).

Keywords: magma eruption rates, eruption styles, preeruptive magma viscosity, transition between explosive and effusive eruption, phenocryst content, bulk rock chemical composition

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-07 Room:315 Time:May 2 10:30-10:45

Conditions for transition from lava dome to explosive eruption

KOZONO, Tomofumi[1*] ; KOYAGUCHI, Takehiro[2]

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

Conduit flow dynamics involving magma vesiculation, gas escape, and crystallization during a lava dome eruption lead to complex processes such as a transition to an explosive eruption. Because the transition from the lava dome to the explosive eruption is accompanied with a drastic increase in eruption intensity, it is important for volcanic hazard mitigation to determine conditions for this transition to occur. In this study, on the basis of a 1-dimensional conduit flow model, we investigated how the conditions for the transition from the lava dome to the explosive eruption depend on magmatic and geological parameters.

In order to systematically investigate the dependence of the transition conditions on the magmatic and geological parameters, we used the relationship between chamber pressure (p_{ch}) and mass flow rate (q) for steady conduit flow (the p_{ch}-q relationship). When the slope of the p_{ch}-q relationship ($\mathrm{d}p_{ch}/\mathrm{d}q$) has a positive value (positive differential resistance), the steady flow is stable. When $\mathrm{d}p_{ch}/\mathrm{d}q$ has a negative value (negative differential resistance), on the other hand, the steady flow is unstable. The negative differential resistance is generated by two positive-feedback mechanisms. First, effective magma viscosity decreases with increasing q because of delay of crystallization, leading to reduced viscous wall friction (feedback 1). Second, magma porosity increases with increasing q because of less efficient gas escape, leading to reduced gravitational load (feedback 2). These two feedback mechanisms induce a sigmoidal p_{ch}-q relationship for some realistic conditions; the positive differential resistance in the low-q and high-q regimes, and the negative differential resistance in the intermediate regime. The analyses of time-dependent conduit flow model indicate that, because of the sigmoidal pch-q relationship, as magma supply at depth gradually increases from the low-q regime to the intermediate regime, magma discharge rate abruptly increases from the low-q to high-q regimes. This abrupt increase in magma discharge rate accounts for the transition from a stable lava-dome eruption to an explosive eruption. We, therefore, define the value of q at the boundary between the low-q and the intermediate regimes as the critical magma supply rate for the transition (q_{cr}).

Our results show that q_{cr} is mainly controlled by the feedback 2 for a wide range of magmatic and geological conditions, whereas it is controlled by the feedback 1 only when phenocryst content is very high. When q_{cr} is controlled by the feedback 2, the value of q_{cr} depends on parameters related to gas escape such as the permeability for vertical gas escape and that for lateral gas escape. We found that for a plausible range of vertical permeability which is constrained from permeability measurements of volcanic rocks, q_{cr} remarkably decreases with decreasing lateral permeability, and it becomes substantially lower than typical magma discharge rates for observed lava-dome eruptions in the limiting case of zero-lateral permeability (i.e. no lateral gas escape). This indicates that the presence of lateral gas escape is a necessary condition for a stable lava-dome eruption to occur. In addition, we found that q_{cr} strongly depends on conduit radius owing to the effects of the change in the conduit radius on the degree of gas escape. As the conduit radius decreases, the ascent of the liquid is suppressed because of the increase in wall friction force, which promotes vertical gas escape. The decrease in the conduit radius also induces an increase in the ratio of the perimeter to the cross-sectional area of the conduit and a decrease in the length scale of pressure gradient that drives lateral permeable gas flow, which promotes lateral gas escape. These promotions of gas escape lead to an increase in q_{cr}. The above results suggest that the variation of conduit radius is a key factor for the transition from a lava-dome to an explosive eruption.

Keywords: conduit flow, numerical model, eruption transition, lava dome, explosive eruption, gas escape

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-08 Room:315 Time:May 2 11:00-11:15

A phreatic explosion model for Mayon volcano, Philippines, inferred from analyses of an explosion earthquake

MAEDA, Yuta[1*] ; KUMAGAI, Hiroyuki[1] ; LACSON, Rudy[2] ; FIGUEROA, Melquiades[2] ; YAMASHINA, Tadashi[3] ; OHKURA, Takahiro[4] ; BORNAS, Antonia[2]

[1]Nagoya University, [2]PHIVOLCS, [3]Kochi University, [4]Kyoto University

Mayon is one of the most active volcanoes in the Philippines with 49 known historical eruptions from 1616 to 2010. A phreatic explosion took place at Mayon on 7 May 2013 that killed five climbers. In this presentation, we show the results of the waveform inversion for the explosion earthquake and discuss a phreatic explosion model for Mayon.

During the explosion in 2013, a VLP event with a peak frequency of 0.4 Hz was recorded by three broadband seismometers which we had installed in 2011. We performed a frequency-domain waveform inversion in 0.1-0.6 Hz, which pointed to a combination of a subhorizontal tensile crack and a vertical single force at a shallow part beneath the summit crater. Contributions from the crack and force to the waveforms had amplitudes comparable to each other.

The source time functions obtained by the waveform inversion are bandpassed forms (filtered source time functions; FSTFs), which may be different from the source time functions without filters (deconvolved forms of the source time functions; DSTFs). Instead of performing numerically unstable deconvolution operations, we assumed simple step- and impulse-type functions with finite durations as candidates of the DSTFs. We applied the bandpass filter to these functions and compared with the FSTFs. The bandpassed waveforms of the impulse-type functions were similar to the FSTFs for both the crack and force, suggesting that the DSTFs can be approximated by the impulse-type functions. The estimated DSTF for the tensile crack showed an inflation followed by a deflation, whereas that for the single force showed a downward force around the time of the maximum opening of the crack.

The RMS seismic amplitudes, GPS baseline lengths over the volcano, ground surface temperatures around the summit, waveform correlations among the seismic stations, the sulfur dioxide emission, and rainfall did not show clear precursory signals.

Since the analyzed VLP event occurred during the phreatic explosion, the initial inflation in the DSTF for the crack may have been caused by boiling of underground water. This crack is subhorizontal and located at a shallow part, suggesting that the crack may be located on a boundary between permeable and impermeable layers where the water may have accumulated and finally boiled, generating the explosion. The downward force may represent the counter force of the explosion. The deflation of the crack in the latter half of the DSTF may have been caused by outgassing of water vapor during the explosion.

The estimated moment amplitude is explained by a volume change of 400 m $\times$ 400 m $\times$ 0.4 m. A topographic change comparable to this crack size was not observed during the explosion, suggesting that the explosion destroyed only a limited portion of the crack. This crack may repeat the explosion once the fragmented portion of the crack is sealed through the hydrothermal alteration. At Mayon, small ash explosions occurred in 2003, 2004, 2006, and 2009, with intervals of a few days to a few years (mostly longer than one month). These intervals are close to experimentally derived time scales of fracture sealing by the hydrothermal alteration; according to the experiments by Berger et al. (1994, Geochim. Cosmo. Acta), who used basalt samples with chemical compositions similar to magmatic eruption deposits at Mayon, a centimeter-order fracture is sealed in two months for 300 ℃ and 54 months for 150 ℃.

In this model, timings of the explosions are controlled by the sealing of the fracture. Therefore the explosions can occur even with a constant supply of heat and water. This may be the reason why no clear precursory signals were observed before the explosion in 2013. No VLP events other than that associated with the explosion in 2013 have been observed at Mayon since the beginning of the observation in 2011, which may be explained by the sealing of the fracture just prior to the explosion.

Keywords: Phreatic explosion, Waveform inversion, Source time function, Hydrothermal alteration

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-09 Room:315 Time:May 2 11:15-11:30

Magma accumulation process of Izu-Oshima volcano, as revealed from deep LF earthquakes, deformation and CO2 out-gassing

WATANABE, Hidefumi[1]*

[1]Disaster Prevention Division, Tokyo Metropolitan Government

In order to make successful mid-term eruption predictions, we need to detect particular precursory processes operating in magma-plumbing system. Since 1989, Izu-Oshima volcano has continued its re-inflation, after the last eruption in 1986, and further repeated deflation-inflation cycles, resulting a net inflation of the volcano. The rate of secular inflation decreased exponentially until 2006, while the amplitudes of the deflation-inflation cycles increased. Since 2007, the rate of secular inflation has kept a constant speed and has also increased the activity of deep low-frequency (LF) earthquakes occurring at the depth range of 30-40 km beneath the volcano. Each episodic LF earthquake activity was preceded by the volcano deflation and accompanied by the inflation. Based on these evidences, we may suppose that the volcano inflation is caused by the supply of magma from a source region at the depth range of 30-40 km beneath the volcano, and that an episodic out-gassing from the shallow magma reservoir triggers each deflation-inflation cycle. To demonstrate the proposed mechanism, we need to combine the data on magma accumulation and out-gassing processes. To monitor the out-gassing of basaltic magma accumulating beneath the volcano, CO_2 is most helpful. In September 2005, we started continuous monitoring of soil CO_2 concentration at the summit of Izu-Oshima volcano, and obtained an evidence for the out-gassing process; the correlated increase of soil CO_2 concentration during the periods of not only accelerated inflation but also deflation of the volcano. Integrating the observational data, we suppose that the rate of magma supply from the upper mantle has increased since 2007 and that the increase in amplitude of deflation-inflation cycles might indicate a volume increase of CO_2 over-saturated region at the upper part of the magma reservoir beneath the volcano.

Keywords: Izu Oshima volcano, eruption prediction, precursors to eruption, volcano deformation, CO2 out-gassing

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-10 Room:315 Time:May 2 11:30-11:45

Spatio-temporal characteristics of volcanic tremor during the 2011 Kirishima eruption by seismic wave analysis

NAKAMOTO, Manami[1*] ; MATSUMOTO, Satoshi[1] ; YAMANAKA, Yoshiko[2] ; SHIMIZU, Hiroshi[1] ; NAKAMICHI, Haruhisa[4] ; ICHIHARA, Mie[3] ; OIKAWA, Jun[3]

[1]SEVO, Kyushu Univ., [2]EVRC, Nagoya Univ., [3]ERI, University of Tokyo, [4]DPRI, Kyoto Univ.

Volcanic tremors are considered as oscillations occurred in magma supply system and provide us important information about condition of the system from magma chamber to crater through a conduit. Therefore, it is important to investigate locations of their source and their characteristics for understanding the condition and process of volcanic activity and modeling the magma supply system. In this study, we reveal features of volcanic tremor using seismic data at Kirishima volcano.

An array observation help us to get information of incident waves on the stations. The two array seismic observations were carried out around Shinmoe-dake during the 2011 Kirishima eruption. One consisted of 25 seismometers located 3 km southwest of the Shinmoe-dake crater (Matsumoto et al., 2013), and the other consisted of 16 seismometers located 5 km northeast of the crater (Nakamichi et al., 2013). The combining data from two arrays enable us to determine the tremor sources. Moreover, we estimated mechanism of the tremor source by using waveforms recorded at temporal seismic station in Kirishima volcanic area and tremor sources obtained by array analysis.

This study focus on the volcanic tremor which occurred on February 2, 2011, and its duration was about 40 minutes. Peak frequencies of the tremor were about 1, 2, 3, and 4 Hz. We investigated temporal variation in the source location of the tremor from the slowness and azimuth of incident wave by MUSIC method. we found that most part of the tremor were radiated around Shinmoe-dake crater. In this part, the tremor that had large slowness and relatively long duration was located in shallow region beneath the crater. In contrast, at some parts of the tremor, source location for waves with short duration were near Ohnami pond, 3.3 km northeast of the crater. Based on amplitude analysis for the seismogram recorded by the seismic network, we also found out difference in radiation patterns of the volcanic tremor among the tremor sources. Assuming single crack model, we found the strike and dip direction of the crack beneath the Shinmoe-dake crater is different from those near Ohnami pond.

Keywords: volcanic tremor, Shinmoedake

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-11 Room:315 Time:May 2 11:45-12:00

Relationship BH-type earthquake swarms and ground deformations prior to eruptions at Showa crater at Sakurajima volcano

TAMEGURI, Takeshi[1*] ; IGUCHI, Masato[1]

[1]DPRI, Kyoto University

Vulcanian eruptions have occurred at the Minamidake crater at the summit since 1955 at Sakurajima volcano. Principal eruptive activity shifted to the Showa crater at the eastern flank of the summit in 2006. The eruptions at the crater become active and minor vulcanian eruptions occurred about 1,000 times per year in 2010-2013. Ash plume height of the eruptions sometimes reached to 3000m in 2013. The eruptive activities at the Showa crater gradually increase.

Inflationary strain changes are observed by extensometers a few tens of minutes to several hours prior to the eruptions and are caused by pressure sources located at depths of 0-1.5 km (Iguchi et al., 2013). The inflation rates decrease or sometimes suspend about 30 minutes before the eruptions. Small earthquakes dominated by high frequency components (5-6 Hz) swarm when duration of inflation is longer than 1 hour. The hypocenters of the earthquakes are located at a depth of 0.5 km beneath the crater and are close to depth of the pressure source. The earthquakes begin to occur a half hour to 1 hour after the start of the inflation. The amplitudes and number of the earthquakes further increase when the inflation rates decrease or suspend. And, the occurrences of the earthquakes suddenly stop at the start of the eruptions. The occurrences of the earthquake swarms are related to the decrease of inflation rate and the long inflation.

Seismic energy releases of the precursory earthquakes related to every eruption accelerate before eruptions. There are all kinds of large and small seismic energy releases in the eruptions. The accelerations of the seismic energy releases before eruptions with explosive events tend to be larger than those with non-explosive events. And, the accelerations of the seismic energy releases are rapid in the case of large deflations after eruptions. The precursory earthquakes may be generated by release of excess pressure accumulated by inflation of the pressure source. We might be able to predict eruption types and scales from occurrence patterns of the precursory earthquakes.

Keywords: Sakurajima volcano, precursory earthquake, ground deformation

SVC50-12 Room:315 Time:May 2 12:00-12:15

Volcanic tremor caused by flow-induced oscillation of a magma-filled dike

SAKURABA, Ataru[1*] ; YAMAUCHI, Hatsuki[2]

[1]Department of Earth and Planetary Science, University of Tokyo, [2]Earthquake Research Institute, University of Tokyo

Volcanic tremor (VT) is known to be long-period and long-duration ground motion generally observed during or before eruptions. Majority of VTs show an emergent onset and, when accompanied with eruptions, an exponentially growing phase in amplitude is typically observed (Konstantinou and Schlindwein 2002; McNutt and Nishimura 2008). This characteristic suggests that VT is manifestation of self-oscillation, in which a persistent steady forcing excites an eigen oscillation of a system and the amplitude exponentially grows until a nonlinear process leads to a limit cycle. In volcanic settings, a steady magma flow through an underground conduit may cause flow-induced self-oscillation of bedrocks, and this is the idea first presented by Julian (1994). In the case of the collapse of Tacoma Narrows bridge, which is known to be caused by flow-induced oscillation, the vibrating bridge can be modeled by an elastic plate placed parallel to an infinite flow. Here we consider a reversed setting: a fluid-flowing thin layer in an infinite elastic body. This system is also unstable if the flow speed is high enough, and may be a generation mechanism of some VTs.

We consider a fluid-flowing plane layer sandwiched between two semi-infinite elastic bodies, expanding Julian's idea to a more general elastodynamic model (for details, see Sakuraba and Yamauchi 2014 to appear in *Earth, Planets and Space*). The eigen oscillation that should be excited in this self-oscillation model is an elastic surface wave. Therefore, we solve the Navier-Stokes equation linearized about a laminar flow with the boundary condition that can maintain a surface wave traveling along the layer. We succeeded in obtaining a complex phase speed of the surface wave as a function of wavenumber (and some parameters) using a shooting method, and found that a relatively slow magma flow could lead to instability in which the imaginary part of the phase speed is positive. Remarkably, the most unstable mode exhibits an antisymmetric (flexural) deformation, which has not been discussed in previous similar studies (Balmforth, Craster and Rust 2005; Dunham and Ogden 2012). The unstable mode is identical to two parallel Rayleigh waves traveling against the basic magma flow. The instability can be understood as acceleration of nearly circular particle motion of the Rayleigh wave due to viscous drag of the main laminar flow. As the critical flow speed giving a neutrally stable state decreases in inversely proportional to wavelength, instability will occur with the largest possible wavelength, which could be several kilometers and produce an oscillation period of around 1 second. In that case, the critical flow speed can be reduced to less than 1 m/s when the magma is basaltic. As the magma flow speed in a dike will not exceed several meters per second, there would be a lower bound in the critical wavelength, producing a period of 0.1 second. Thus our model naturally explains typical periods of 0.1-1 seconds observed on volcanoes. Our model also explains typical timescales of the linearly growing phase in some VTs.

SVC50-13 Room:315 Time:May 2 12:15-12:30

Magnitude-frequency distribution of volcanic eruptions from an open conduit

NISHIMURA, Takeshi[1*] ; IGUCHI, Masato[2] ; MUHAMAD, Hendrasto[3] ; AOYAMA, Hiroshi[4]

[1]Science, Tohoku Univ., [2]DPRI, Kyoto Univ., [3]CVGHM, Indonesia, [4]Science, Hokkaido Univ.

Explosive eruptions such as vulcanian, strombolian, or significant gas burst excite seismic waves. Such seismic signals, which are often called as explosion earthquakes or explosion quake, are used to quantitatively evaluate the magnitude of such volcanic explosions. In the present study, we systematically examine magnitude-frequency distributions of explosion earthquakes observed at Sakurajima and Suwanosejima volcanoes in Japan, and Semeru and Lokon volcanoes in Indonesia. We use the long-term catalog data of Sakurajima explosions for the period from 1963 to 2011, which are routinely summarized by Sakurajima Volcano Research Center (SVRC). Also, we measure the amplitudes of explosion earthquakes from continuous seismic records observed at Suwanosejima and Semeru and Lokon volcanoes in Indonesia. We measure the number of earthquakes that exceed a given amplitude, and then plot the cumulative number of earthquakes versus amplitude, as is often done for examining Ishimoto-Iida's relation, which expresses a power law distribution. However, the observed frequencies of earthquakes at the four volcanoes do not seem to fit the Ishimoto-Iida's relation. The cumulative numbers are well explained by exponential functions. This means that the magnitude of explosion earthquake at each volcano is randomly determined with an average scale.

Keywords: Volcanic Explosion, Vulcano, Gas burst, Magnitude-frequency distribution

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-14 Room:315 Time:May 2 14:15-14:30

Rheological transition of plagioclase-bearing magma: high-temperature uniaxial deformation experiments of sanukite lava

ISHIBASHI, Hidemi[1*]

[1]Graduate School of Science, Shizuoka University

High-temperature uniaxial compression experiments were done for bubble- and phenocryst-free, plagioclase-bearing lava to investigate the effect of tabular crystals on rheological properties of highly crystalline magma. High-Mg andesite lava from Goshikidai lava plateau, southwest Japan, was used for starting material. The lava is bubble- and phenocryst-free, composed of 60 vol.% rhyolitic glass, 36 vol.% of tabular plagioclase and 4 vol.% of pyroxenes and magnetite and plagioclase crystals are well aligned parallel. High-temperature uniaxial defomation apparatus at Earthquake Research Institute, the University of Tokyo, was used for experiments. The lava was cut to 10 x 10 x 20 mm rectangular solids and deformed under conditions of temperatures of 1238, 1188, and 1138 K and deformation rates from 3.16 to 0.003 mm/min. Run samples were quenched and processed to thin section for textural and compositional analyses by using EPMA.

Phase proportions in all run samples were the same as that of starting material, indicating crystallization did not occur during experiments. The lava behaves as shear thinning fluid under all temperature conditions. Viscosity at strain rate of 10^{-4} s^{-1} increases from $10^{8.7}$ to $10^{9.4}$ Pas with decreasing temperature. Power law exponent [= d(log viscosity)/d(log strain rate)] is ca. 0.64, which is consistent with extrapolation of previous studies for natural plagioclase-bearing magmas. Relative viscosity [= (bulk viscosity)/(melt viscosity)] is ca. $10^{2.4}$ at strain rate of 10^{-4} s^{-1} under all temperatures, indicating that the concept of relative viscosity works well under present experimental condition. The relative viscosity-crystal fraction relation is also consistent with extrapolation of previous studies for natural plagioclase-bearing magmas. Marron-Piece equation well explains the relation with the maximum packing fraction of 0.43. Present results suggest that rheological transition occurs at crystal fraction near 0.43 for plagioclase-bearing natural lava in which plagioclase crystals are well aligned parallel. The value is higher than ca. 0.3 proposed by Picard et al. (2013)'s experiments in which plagioclase orientation is random in starting materials, indicating the first order importance of plagioclase orientation distribution on rheological transition.

Keywords: rheological transition, viscosity, magma, plagioclase, non-Newtonian fluid, sanukite

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-15 Room:315 Time:May 2 14:30-14:45

Conduit flow of silicic magma: Viscous flow or Frictional sliding?

OKUMURA, Satoshi[1*] ; UESUGI, Kentaro[2]

[1]Department of Earth Science, Graduate School of Science, Tohoku University, [2]Japan Synchrotron Radiation Research Institute

Outgassing rate and bulk magma viscosity that control the style of volcanic eruptions depend on flow type of magma ascending in a volcanic conduit. When magma behaves as a Newtonian fluid, magma in the conduit experiences shear strain large enough to cause effective outgassing. On the other hand, once shear starts to localize, bulk magma viscosity may decrease due to slip deformation and outgassing rate also decreases in parts other than shear-localized region (Okumura et al., 2013 EPSL). Silicic magma experiences shear-induced brittle fracturing and subsequent frictional sliding along the fracturing zone during its ascent (e.g, Gonnermann and Manga, 2003 Nature; Tuffen et al., 2003 Geology). Therefore, outgassing rate and bulk magma viscosity during the ascent are expected to change dramatically. Previous studies (Tuffen et al., 2003 Geology; Gonnermann and Manga, 2005 EPSL) also proposed that fractured magma can heal during magma ascent and that fracturing and healing processes may control the dynamics of magma ascent. In contrast to this model, some experimental studies (e.g. Okumura et al., 2010) indicated that fractured magma cannot heal as long as the deformation continues. In this study, we perform deformation experiments for fractured magma to investigate flow type of magma in the conduit, i.e. viscous flow or frictional sliding, and controlling factors of the transition from viscous flow to frictional sliding.

The deformation experiments were carried out using a custom-made torsional deformation apparatus which was installed in synchrotron radiation X-ray imaging system (BL20B2) of SPring-8. To simulate fractured silicic magma, we crushed rhyolite obsidian and sorted them into fragments of 75-250 μm in size. The powdered sample was sandwiched by two obsidian discs and they were twisted by rotating a piston attached with a rotational motor. The torsional deformation experiments were performed at temperatures of 800 and 900 ℃ under 1-10 MPa pressures. The rotational rate was set to be 0.1 to 10 rpm, corresponding to strain rates of 10^{-2} to 1 s^{-1} if the sample deforms homogeneously. The deformed samples were observed in situ using an X-ray radiography.

At a temperature of 900 ℃ and rotational rates of 0.1-1 rpm, homogeneous deformation through a sample was observed under a pressure of 10 MPa, which indicates viscous deformation. In contrast, the sliding at the interface between powdered obsidian and the disc was observed under 1 and 5 MPa pressures. At a temperature of 800 ℃, the sliding was found under 1-10 MPa pressures. These results indicate that frictional sliding along fractured zone is flow type of magma in shallow parts of the conduit ($<$10 MPa).

We assume that flow type is determined by competition of shear stress necessary for viscous flow and frictional sliding. If magma has high viscosity and shear stress to deform a sample viscously is large, the flow type becomes frictional sliding. At a temperature of 900 ℃, viscous flow and frictional sliding were found at 10 and 1-5 MPa pressures, respectively. At this condition, magma viscosity is approximately 10^7 Pa s (Hess and Dingwell., 1996) and shear stress necessary for viscous deformation is 1 MPa at a strain rate of 0.1 s^{-1}. Because the frictional sliding was observed at pressures of 1-5 MPa, the frictional coefficient is estimated to be ca. 0.1. When we use this value and the criterion for shear-induced brittle fracturing proposed by Okumura et al. (2010), the dynamics of magma ascent is controlled by frictional sliding at shallow parts of the conduit. In addition, silicic magma can ascend quickly due to low frictional coefficient of fractured magma.

Keywords: Silicic magma, Volcanic eruption, Viscous flow, Frictional sliding, Synchrotron radiation X-ray

SVC50-16 Room:315 Time:May 2 14:45-15:10

Mechanism of delayed brittle-like fragmentation of vesicular magma analogue

KAMEDA, Masaharu[1*] ; SHIDA, Tsukasa[1] ; ICHIHARA, Mie[2] ; TSUGO, Mitsuaki[1] ; OKUMURA, Satoshi[3] ; UESUGI, Kentaro[4]

[1]Mech. Sys. Eng., TUAT, [2]ERI, Univ. of Tokyo, [3]Earth Sci., Tohoku Univ., [4]JASRI

Magma fragmentation is a key phenomenon controlling volcanic eruptions. The fragmentation is classified into two styles: solid-like brittle fragmentation and liquid-like ductile fragmentation. Brittle fragmentation is more hazardous than ductile fragmentation because violent release of pressurized gas in the bubbles contained in the magma may lead to explosive eruptions

The fragmentation of magma, which is a viscoelastic fluid, occurs through a combination of viscoelasticity and rapid deformation. We conducted a rapid decompression experiment over ten years in order to clarify the viscoelastic effect on the fragmentation using a magma analogue, syrup containing gas bubbles (Kameda et al GRL 2008; Kameda et al. JVGR 2013).

Through the experiment we demonstrated the existence of a transitional fragmentation behavior. This transition behavior, which we refer to herein as brittle-like fragmentation, occurred even if the response of material should be in a ductile manner. Comparing the realistic decompression time with the viscoelastic relaxation time for magma, it is more probable that the fragmentation in the real volcanic system occurs in a brittle-like manner.

Observation by high-speed photography using a visible light-source indicated that the onset of brittle-like fragmentation was triggered by the sudden release of a considerable amount of gas from a crack in the specimen. Further observation (Shida et al. IAVCEI 2013) showed that reducing the volume of the specimen suppressed the onset of fragmentation even if their brittleness (Ichihara and Rubin 2010) was close to unity. In our case, the pore distribution of the small samples was more uniform than that of large samples. This observation implies that the crack is initiated from the interior of the specimen due to non-uniform spatial distribution of bubbles.

Then, we observed the interior of the specimen by synchrotron X-ray tomographic microscopy. The X-ray tomographic microscopy was performed at the BL20B2 beamline of the Japan Synchrotron Radiation Research Institute (JASRI, Hyogo, Japan). Initial structure of the specimen was observed by three-dimensional tomographic imaging. High-speed radiography was performed during the decompression. A digital charge-coupled device (CCD) camera was used as the detector whose imaging area is about 16 mm (horizontal) by 5 mm (height) with spatial resolution of 8 μm/pixel. We took 1800 projections over 180 degrees of rotation for tomographic imaging. The framing rate of radiography is 200 frames per second. We successfully captured a series of images during the brittle-like fragmentation. The reconstructed 3D image of the specimen indicated that the brittle-like fracture was initiated at a notch and a chain of small bubbles in the vicinity of a large bubble.

We propose the following scenario for brittle-like fragmentation: It is initiated from ductile growth of internal cracks by connection of bubbles. The stress concentration and the brittleness at crack tip may exceed the critical level at some moment, which leads to brittle failure of the crack. Rapid decompression due to sudden release of a considerable amount of gas from the crack may increase local brittleness to cause partial fragmentation. Such a sequence from ductile crack growth to partial fragmentation may successively occur in brittle-like fragmentation.

Keywords: Magma, Fragmentation, Viscoelasticity, Decompression, X-ray CT

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SVC50-17 Room:315 Time:May 2 15:10-15:35

Approach by volcanic observation for dynamics of volcanic phenomena

IGUCHI, Masato[1]*

[1]DPRI, Kyoto University

Dynamics of volcanic activity has been revealed by various kinds of observation. Inflation of volcanic body prior to eruptions corresponds to intrusion of magma to the underground of volcanoes and deflation is accompanied by eruptive activity.

Prior to vulcanian eruptions, minor deflation is detected. This corresponds to leakage of volcanic gas from a gas pocket formed at the uppermost conduit. The minor deflation reflecting minor pressure decrease induces a sudden degassing in oversatulated magma. The sudden degassing corresponds to a volume increase at a deep part in the conduit, as revealed by outward first motions of explosion earthquakes. The volume increase attained at the top of the conduit and the gas pocket overbursts. As the results of collapse of the gas pocket, infrasound of air-shock type is generated with ejection of incandescent bombs followed by ejection of volcanic ash.

Keywords: vulcanian eruption, Sakurajima