Two positive-feedback mechanisms controlling the bifurcation of gas-escape processes during volcanic eruptions

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The dynamics of conduit flow is affected by density change of magma due to gas-escape and viscosity change due to crystallization. The processes of gas-escape and crystallization, therefore, lead to diverse features of volcanic eruptions such as a transition from a lava-dome forming eruption to an explosive eruption. The diverse features of eruption sequence are investigated using a model of magma plumbing system composed of a conduit and a magma chamber in elastic rocks, in which the effects of lateral and vertical gas-escape, as well as that of crystallization, are taken into consideration (Kozono and Koyaguchi, 2012). Here, using this model, we estimate the effects of gas-escape on the diverse features of eruption sequences.

Generally, the dynamics of conduit flow is controlled by the relationship between chamber pressure (P) and mass flow rate (Q) for steady conduit flow (the P-Q relationship). The diverse features of eruption sequence can be explained by the variation in the P-Q relationship. The variation in the P-Q relationship can be systematically described using the two reference relationships of extreme cases: the efficient gas escape (EGE) case and the no gas escape (NGE) case. The P-Q relationship for general cases is located between the EGE and NGE cases. In the P-Q relationship for general cases, there are two mechanisms that cause a transition from the EGE case to the NGE case and bring forward its change (the two positive-feedbacks).

The first positive feedback occurs during the waxing stage of an eruption. As the magma flow rate, Q, increases in the waxing stage, magma porosity increases with increasing Q because of less efficient gas escape, which leads to further increasing in Q because of reduction of gravitational load. This feedback mechanism causes complex dynamics; Q changes abruptly and/or cyclically even if magma supply at depth gradually increases. This abrupt increase in Q may account for the transition from a stable lava-dome eruption to an explosive eruption.

The second positive feedback occurs during the waning stage of an eruption. During the waning stage, as the chamber pressure, P, decreases, the pressure inside the conduit also becomes lower than the lithostatic pressure. The decrease in pressure inside the conduit reduces the efficiency of the lateral gas escape. This reduction of lateral gas escape increases magma porosity, which, in turn, leads to a decrease of the gravitational load and a further decrease in P. This feedback mechanism is particularly important in the sense that it controls the magnitude of decrease in chamber pressure during eruption (i.e., pressure drop), and hence, the scenario towards the end of an eruption.

Results of an extensive parametric study indicate that whether the second feedback mechanism plays a role or not is sensitive to a slight change in the permeability of the country rocks. For the condition where this feedback does not work, an eruption ends when the initial overpressure of magma chamber is relaxed. When this feedback plays a role, on the other hand, even after the initial overpressure of magma chamber is relaxed, an eruption continues until the chamber pressure becomes as low as the static pressure of gas-rich magma.

Keywords: magma plumbing system model, gas-escape process, eruption sequence, bifurcation

Mechanisms of transitions in eruption style at the end of the 1912 eruption of Novarupta, volcano, Alaska

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The 1912 Novarupta eruption consisted of five episodes ranging from strong Plinian (mass eruption rates of 1.1 –5 x 10^8 kg/s) to stable, steady dome effusion. Sixty hours of Plinian explosions erupted first predominantly rhyolite (Episode I) and then dacite with minor amounts of andesite (Episode II-III). Episode IV produced a dacitic block bed, interpreted as the product of complete destruction of a dacite plug/dome via Vulcanian explosions, before extrusion of a rhyolite dome in Episode V.
The transition in style and intensity from powerful explosions to dome growth is represented by three shifts in eruption style. We describe here the mechanisms of the first two shifts (lower Episode III to upper Episode III and upper Episode III to Episode IV).

The switch from sustained Plinian eruption to an unsteady subplinian phase during Episode III was brought about by progressive increase in the level of outgassing of the dacite melt remaining in the conduit. This is seen in a steady increase in the amount of dense dark grey juvenile ejecta as the outgassed melt slowed the rate of magma ascent and began to ‘choke’ the shallow conduit. The deposits are well bedded and markedly less dispersed than the Plinian falls of episodes I, II and early Episode III.

The second shift was from unsteady subplinian eruption (end to Episode III) to non-sustained transient Vulcanian explosions in Episode IV. Highly diverse juvenile blocks from Episode IV provide special insight to the state of the magma as an eruption passes from powerful sustained Plinian eruption to passive dome growth. They supply a picture of a dynamic and complex shallow conduit, now dominated by partially or completely outgassed dacitic melt that was resident at shallow levels, prior to fragmentation in repeated small Vulcanian explosions. Small total and individual explosion volume estimates, suggest that individual explosions during Episode IV disrupted the conduit to only shallow depths. Our data (1) suggest that different explosions tapped small yet diverse parts of the conduit’s architecture and (2) require a more complex model than repeated progressive evacuation in a top-down fashion of a simple horizontally stratified magma-filled conduit. The shallow conduit architecture involved both the juxtaposition of domains of contrasting texture and vesiculation state and the intimate mingling of different textures on short vertical and horizontal length scales at the contacts between these domains.

Keywords: Plinian, Vulcanian, transitions in explosive eruptions

What can "nanolites" tell us about eruption styles?

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Crystallization of groundmass minerals record physicochemical conditions of magmatic processes upon eruption. Mujin and Nakamura (2014) reported that different assemblages of the nanolites in pyroclasts of the 2011 eruption of Shinmoedake, the Kirishima volcano, recorded the bifurcation conditions of the eruption styles. The pyroxene nanolite crystallized in both of the sub-Plinian products and the lava extrusion and Vulcanian products of the 2011 activity, whereas the plagioclase nanolite followed that of pyroxene only in the lava extrusion and Vulcanian products. They pointed out that the presence of plagioclase nanolites indicates the prolonged residence (or transit) time in the shallow conduit or crater (under large ΔT) at magmatic temperature prior to the lava extrusion and the Vulcanian explosions. The lack of plagioclase nanolite gives the upper limit of the duration in which the magma ascent through the shallow conduit in the sub-Plinian eruptions, whereas the appearance of plagioclase nanolite gives the lower limit of magma residence time for Vulcanian explosions.
Following their study, we report the presence of nanometer-scale crystals down to 1 nm in the pyroclasts from the Shinmoedake 2011 eruption and their mineralogical characteristics based on field emission-scanning electron microscopy and transmission electron microscopy.
The main finding regarding nanolite crystallization is a gap (hiatus) from ~100 to 30 nm in the size distribution of pyroxene in a dense juvenile fragment of a Vulcanian explosion. The finer-sized crystals of ~20–30 nm were defined as "ultrananolites." In the dense fragment sample, bright spots of ~1–2 nm in diameter were recognized in high-angle annular dark-field scanning transmission electron microscopy images. These spots are presumed to be Fe–Ti oxide, although their mineral phase was not determined due to their small size. If so, the 1–2 nm crystals are ultrananolite with a ~9 nm gap from titanomagnetite nanolites. The pyroxene ultrananolite and Fe–Ti oxide nanolite and ultrananolite are assumed to have been formed by the additional increase in ΔT through cooling and oxidation, possibly by fragmentation followed by rewelding at the crater. Another important finding is that crystals smaller than a few tens of nanometers for pyroxene and a few hundred nanometers for plagioclase did not exist (or their number densities were too low for accurate determination). This indicates presence of practical minimum size of the crystals. These observations show that nucleation of the nanoscale crystals ceased, at least practically, in the late stage of groundmass crystallization owing to increased interfacial energy and decreased melt diffusivity in a dehydrated melt, whereas crystal growth was mostly continuous. The observation that pyroxene crystallization practically ceased before plagioclase nanolite appeared is consistent with the similarity in pyroxene characteristics such as the minimum crystal size of nanolite and the boundary size between microlite and nanolite between sub-Plinian and Vulcanian products, although plagioclase nanolites are found only in the Vulcanian products. The differences in the conditions between lava extrusions and Vulcanian explosions may be recorded in the later stage crystallization of plagioclase and Fe-Ti oxides.

Chlorine mapping as a new tool to investigate the degassing processes of silicic magma

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Vesiculation, outgassing and foam collapse are considered to be the primary control of eruption styles. However, the detailed mechanism of these processes is poorly understood. One possible way to explore this is to use the chlorine content mapping of the groundmass glass: Because of its low diffusivity, chlorine may maintain the disequilibrium distribution produced during the degassing processes. Therefore, the chlorine distribution potentially provides information about the degassing history during ascent. To examine this possibility, we carried out vesiculation and bubble resorption experiments of rhyolitic melt, and analysed the chlorine content around bubbles using an FE-EPMA. Experiments were carried out by heating hydrous rhyolitic obsidian in an open-system capsule at 1000 degC and 10-30 bar for 3-24 h. The run products showed a structure of two distinct regions: One is the bubble-rich core and the other is the bubble-free margin. The bubble-free margin is the product of bubble resorption caused by diffusive dehydration (Yoshimura and Nakamura, 2008). In the bubble-rich core, chlorine diffused towards bubbles, showing that these bubbles are absorbing chlorine during growth. The outermost bubbles are those dissolving in the undersaturated melt. These bubbles had high-Cl corona, indicating that these bubbles discharge chlorine during resorption. In the bubble-free margin, circular spots with high chlorine contents were observed. These spots represent the remnant of dissolved bubbles. These results suggest that chlorine mapping may be a powerful tool to decipher the history of degassing processes in ascending magma.

Keywords: chlorine, vesiculation, bubble resorption

Orientation of eruption fissures controlled by shallow magma plumbing system; example of the fissure pattern in Miyakejima

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Orientation of the eruption fissures and composition of the lavas of the Miyakejima volcano indicate the competitive processes of the regional tectonic stress and the local stress generated by the activity of a magma plumbing system beneath the volcano. We investigated the distributions and magmatic compositions of the recent 23 fissures that formed within the last 2800 years, based on a field survey. Some fissures are also confirmed their eruption date by new datasets of ^{14}C ages. The result highlights the tectonic influence of shallow magma chamber on the development of feeder dikes in a composite volcano.
As previously known, the dominant orientation of the eruption fissures in the central portion of the Miyakejima volcano was NE-SW during the last centuries, which is perpendicular to the direction of regional maximum horizontal compressive stress (σ_{Hmax}) indicated by the regional seismicity. Our field survey reveals that the magmas that show evidence of mixing between basaltic and andesitic compositions erupted mainly from the eruption fissures with a higher offset angle from the regional σ_{Hmax} direction.
The dike pattern perpendicular to the direction of maximum compression σ_{Hmax} is an unusual and uncommon feature in volcanoes. The distribution and magmatic compositions of the eruption fissures in Miyakejima volcano can be explained by the tectonic influence of shallow magma chamber on the development of feeder dikes in a composite volcano. The presence of a shallow dike-shaped magma chamber controls the eccentric distribution of the eruption fissures perpendicular to the present direction of σ_{Hmax}. Injection of basaltic magma into the shallow andesitic magma chamber caused the temporal rise of internal magmatic pressure in the shallow magma chamber which elongates in NE-SW direction. Dikes extending from the andesitic magma chamber intrude along the local stress field which is generated by the internal excess pressure of the andesitic magma chamber. As the result, the eruption fissures trend parallel to the elongation direction of the shallow magma chamber. The dikes propagated from the andesitic magma chamber provide the evidences for magma mixing between the stored andesitic and injected basaltic magmas. Some basaltic dikes from the deep-seated magma chamber reach the ground surface without intersection with the andesitic magma chamber. These basaltic dikes develop parallel to the regional compressive stress in NW-SE direction. The patterns of the eruption fissures can be modified in the future as was observed in the case of the destruction of the shallow magma chamber during the 2000 AD eruption.

Keywords: eruption, eruption fissure, magma chamber, dike, Miyakejima

Numerical investigation of temporal changes in field observations associated with volcanic hydrothermal systems during inter-eruptive stages

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Localized temporal changes in the magnetic field and coincident ground deformation are often observed at volcanoes that have fumarolic activities (Mt. Tokachidake, Mt. Meakandake, Mt. Tarumae, Kuchinoerabujima volcano, etc.). This study focuses on two mechanisms that may bring about some changes in hydrothermal system during inter-eruptive stages: (1) permeability reduction at the shallow part of the conduit, and (2) fluctuation of hydrothermal fluid flux from a deeper part. Numerical calculation serves as a platform for systematic investigation of the surface responses to these mechanisms. We classify the pattern of temperature and pore pressure changes as well as the resulting magnetic total field, fumarolic heat discharge, and possible ground deformation that are associated with the conduit constriction and/or fluctuating flux of hydrothermal fluid by means of hydrothermal numerical simulation.

We used the numerical code “STAR” with the equation-of-state “BRNGAS” (Pritchett, 1995). It enabled us to calculate the heat and mass flow rate of H_2O (vapor, liquid and two-phase) and Air in porous media over a temperature range 0–350 ºC. The calculation region was set as axisymmetric 2D to represent a simplified conical edifice. The edifice (host rock) had a uniform porosity and permeability. Temperature and pressure were maintained constant at the ground surface and on the vertical boundary of the downstream side. Thermally insulating and hydraulically impermeable conditions were imposed at the bottom boundary. Meteoric recharge was injected at the land surface at a constant rate and a constant heat flow was supplied at the base of the model. The high-permeability conduit was introduced at the axis of symmetry, hydrothermal fluid is injected at the bottom of the conduit to reproduce fumarolic heat discharge of about 100 MW, after reaching a quasi-steady condition. Thereafter, an abrupt reduction of permeability at a particular depth (PCB) in the conduit (conduit obstruction) and/or an increase in the flux of hydrothermal fluid at the bottom of conduit (increase in hydrothermal-fluid-flux) were imposed, and the system response is observed.

Conduit obstruction caused reduction in temperature and pore pressure above PCB, and increase in temperature and pore pressure below PCB. Meanwhile, increase in hydrothermal-fluid-flux induced heat accumulation and pore pressure increase around the conduit. When conduit obstruction and increase in hydrothermal-fluid-flux are introduced at the same time, whether temperature and pore pressure above PCB increase was influenced by the balance between the amount of permeability reduction of PCB and the amount of increase in flux of hydrothermal fluid. However, when the permeability of PCB after reduction was smaller than the permeability of host rock, temperature and pore pressure decrease above PCB regardless of the amount of increase in hydrothermal-fluid-flux.

In the presentation, we will discuss the change in total magnetic field, ground deformation, and fumarolic heat discharge by using these changes in temperature and pore pressure. In addition, we will try to investigate the influence of parameters such as host-rock-permeability, depth of PCB, the construction of permeability and porosity in the edifice.

Keywords: hydrothermal system, hydrothermal sealing, numerical simulation

