# Statistical classification of tephra from rootless eruptions

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Rootless cones (RCs) are classified into a peculiar type of pyroclastic cones formed by lava-water interaction (Thordarson and Hoskuldsson, 2002). Different from other cone-forming eruptions the size is generally small so that they can be used as a miniature of volcanic eruptions which unite between large scale natural eruptions and laboratory scale experiments. In this context, the data about the morphology of the edifice as well as physical characteristics of eruption products (hereafter called as rootless tephra) are important in the comparison although the available data are quite limited until recently. In the recent decade there appear several researches on the RCs in Iceland mainly from planetological interests (Reynolds *et al.*, 2015; Noguchi *et al.*, 2016; Hamilton *et al.*, 2017; Fitch *et al.*, 2017). Fitch *et al.*, 2017 investigated detailed grain morphology of rootless tephra and found correlation among mean grain size and tephra morphologies; blocky, mossy, fluidal, shard, and aggregate. The study is based on the analysis of morphological classification for about 100 hand-picked grains. The results seem interesting but always associated with morphological investigations the limited numbers of specimens and the sampling uniformity are controversial.
In this study we investigated morphology of rootless tephra by using automated particle-morphology analyzer. Thanks to the recent advances of the device, we can obtain information of morphology for thousands of grains in a short time. By using this device we try to overcome the above-mentioned problems. The target samples were collected in three fields of RCs in Iceland (Myvatn, Landbrot and Thjorsardalur). We used seven parameters to characterize the morphology: aspect ratio, circularities (circularity and high-sensitivity one), convexity, solidity, intensities (mean and standard deviation) which are measured on Morphologi G3S$^{TM}$ (an automated particle analyzer, Malvern Instrument$^{TM}$) in AIST. The target of this investigation is to explore the magnitude of lava-water interaction of rootless eruptions in comparison with other phreatomagmatic/phreatic eruptions based on the morphology of tephra.
In the analysis we seek possible correlations between morphological parameters and the magnitude of rootless eruptions (volume and average slope of the cone). We found that transparent elongated-irregular shaped grains are notable in the samples which were collected from the lower layer of RCs. Looking at the images of specimen, these grains include bubbles and/or bubble walls. This might indicate the lava which was still at the degassing stage was quenched and fragmented at the beginning of rootless eruptions. To verify this idea, the bubble and crystal size and density analyses are necessary.

キーワード：ルートレステフラ、粒子形状、クラスター分析
Keywords: rootless tephra, grain shape, cluster analysis

 

# Constraints on the chemical evolution of magma at Fuji volcano from plagioclase phenocrysts.

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Volcanic eruption brings materials from inside the Earth to the surface. Studying such volcanic materials is important to know how magma is evolved and how eruption is triggered. Chemical evolution of magma is considered to proceed through various processes such as fractional crystallization, degassing, assimilation and mixing. In this study, we have conducted petrology, geochemistry and Sr isotopic study of plagioclase phenocrysts to constrain the chemical evolution at Fuji volcano in Japan.
The studied samples are basaltic lavas, gabbros, pumices, and scoriae from Fuji volcano. All the samples except the lavas are products of the latest eruption, the Hoei eruption in 1707. Pumices and scoriae of the Hoei eruption were collected from three outcrops and scoria cone in the first crater of the Hoei eruption. Gabbroic xenoliths brought by Hoei eruption were also collected near the second crater. In addition, two lava samples which belong to Kofuji group were collected by drilling into the northwestern flank of Fuji volcano (Yoshimoto et al., 2010).
Major element compositions of plagioclase phenocrysts from the samples were determined by EPMA, whereas their trace element abundances and Sr isotopic composition were measured by LA-ICPMS at the University of Tokyo. In addition, water contents in some plagioclase phenocrysts were investigated by FTIR at JAMSTEC.
The results revealed that there are two distinctive trends for the chemical evolution of magma at Fuji volcano ( Fig.a). One is characterized by the decrease of anorthite content (An) with the increases of La abundance and Eu-anomaly in plagioclase crystals. The other trend is characterized by the decrease of An with the increase of Mg abundance and with insignificant changes of La abundance. The former evolutionary trend was observed mainly in the gabbro xenoliths and Hoei pumices, whereas the latter was identified in the basaltic lavas and Hoei scoriae. The finding suggests that the source magmas of the gabbros and Hoei pumices evolved under similar conditions and those of the lavas and Hoei scoriae did so as well. This is consistent with the inference that the dacitic and basaltic source magmas of the Hoei pumices and scoriae existed in different magma chambers(e.g. Yoshimoto et al., 2004).
The negative correlation between An and Eu-anomaly observed in the gabbro and pumice plagioclase indicates that their source magmas became more reductive so that the proportion $Eu^{2+}$ relative to $Eu^{3+}$ increased as crystallization proceeds. Such reduction of magma can be caused by assimilation of sediments enriched in organic materials or by sulfur degassing (Moussallam et al., 2016). Our Sr isotopic analyses indicate that the core and rim of the plagioclase have identical Sr isotopic ratios within analytical uncertainty, precluding significant sediment assimilation. Thus, we envisage that the source magmas of the gabbros and Hoei pumices experienced degassing during the chemical evolution.
Our FTIR analyses revealed that plagioclase crystals in the Hoei pumices and scoriae have water under the detection limit (sample thickness: 100 micro-meter). The IR spectra of plagioclase crystals exhibit flat spectra between 3000 and 4000 $cm^{-1}$. This is somewhat enigmatic, given that the studied pumices and scoriae contain many vesicles and also that glass-inclusions of the Hoei scoriae contain 1~4 wt % $H_2O$

 

(Iida et al., 2004). There is no clear explanation for this at present.

キーワード：火山、宝永噴火、斜長石、水
Keywords: volcano, Hoei eruption, plagioclase, water

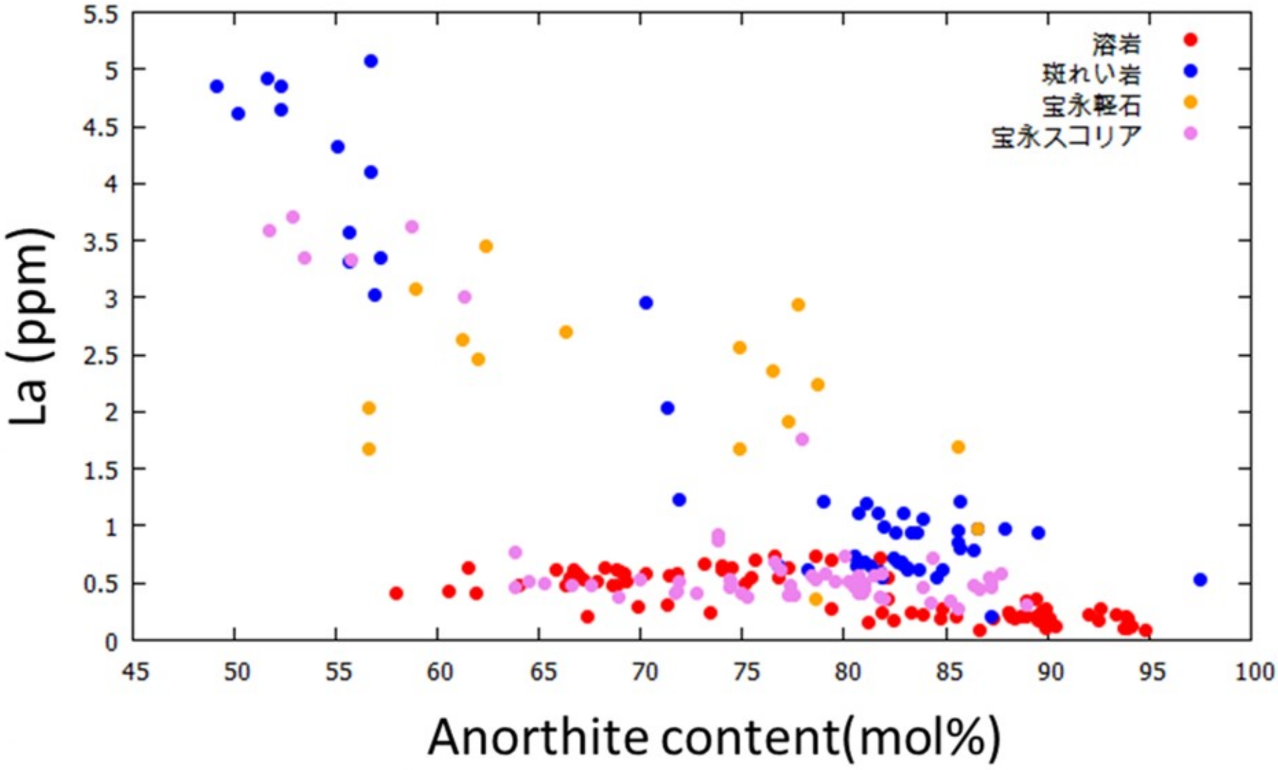


Fig. a

 

# Model experiments of degassing process in a crystal bearing magma

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Degassing from an ascending volatile-rich magma affects the style of volcanic eruption. Eruption is considered to become explosive when the magma viscosity is high because degassing is difficult. However as solidification progresses, cracks may form in the pathway of the bubbles such that the degassing is promoted. Then the eruption may become effusive. Magma contains crystals and becomes non-Newtonian such that the viscosity decreases with the strain rate (a shear-thinning property). Divoux *et al.* (2011) conducted degassing experiments using a non-Newtonian fluid (a diluted solution of a commercial hair-dressing gel), and showed that several distinct styles of degassing styles exist. However, there have been no degassing experiments in which ascending bubbles are directly observed in a fluid containing liquid and particles. In this study we inject bubbles into a transparent mixture of liquid and particles which models a crystal-bearing magma. We vary the particle volumetric fraction *phi* to understand how the degassing regimes transition as *phi* increases.

A transparent model fluids are made by mixing a silicone powder (particles) and a silicone oil which has the same refractive index. The volumetric fraction *phi* of the particles range from 0 to 0.5. From the rheology measurements, we find that the viscosity and the yield stress increases with phi. In addition the fluid becomes increasingly shear thinning with *phi*.

In this study, we conduct two types of experiments. Experiment 1 is conducted to study how the bubble ascent velocity ($U$) depend on its volume ($V$). Experiment 2 is conducted to observe the pattern of the bubbly flow and the fluctuations of differential air pressure at several flow rates $Q$. From experiment 1 (*phi* = 0-0.4), we find that $U$ decreases with *phi*. We fit the data to a power-law relation ($U$ *proportional to* $V^n$) and obtain the power-law exponents $n$, for each fluids with different *phi*. From the Stokes' law, $n$ in a Newtonian fluid is $n$ = 2/3 ~ 0.67. At *phi* = 0, 0.1 we find that $U$ is smaller than the Stokes' velocity and that $n < 0.67$. Reynolds number ($Re$) in these experiments are $Re$ ~ 100 which is much larger than 1, and we consider that the turbulent drag is the cause of this deviation. On the other hand for *phi* = 0.3-0.4, $U$ becomes sufficiently small such that $Re < 1$. The value of the exponent $n$ is $n > 0.67$ and the measured $U$ agree well with the Stokes' velocity calculated using the shear-thinning viscosity. Here we note that $n$ increasing with *phi* implies that the coalescence of bubbles with different sizes are enhanced, which we confirmed in our experiments. For fluid with *phi* = 0.5, we find that the bubble ascent is strongly inhibited because the yield stress becomes comparable to the bubble buoyancy. From experiment 2 (*phi* = 0.4-0.5), we observe that the generation and coalescence of the bubbles occur continuously. As $Q$ increases, the bubbles become larger and vertically elongated (slugs). Furthermore, at *phi* = 0.5, narrow cracks form near the orifice where the bubbles form. The style of the differential pressure fluctuations also change with *phi*. At *phi* = 0.4, the pressure fluctuates regularly having a short period. However at *phi* = 0.5, the fluctuation becomes irregular with a longer period.

Our experiments suggest that as the magma cools and *phi* increases, the bubble ascent velocity becomes slower, such that the bubbles may even become trapped. However if the bubble size exceeds a critical value such that they can ascend, at large *phi* coalescence of bubbles with different sizes are enhanced which promotes degassing. Our experiments also show that whenever a bubbly flow occurs, an increase in *phi* results in an irregular, long period pressure fluctuations, which may excite volcanic tremors having similar temporal features.

 

キーワード：マグマ、脱ガス、ずり流動化、モデル実験、体積分率、気泡
Keywords: magma, degassing, shear-thinning, model experiment, volumetric fraction, bubble

# Visualization of the rapid crack propagation driven by a pressurized air in viscoelastic gels

Visualization of the rapid crack propagation driven by a pressurized air in viscoelastic gels

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Sudden expansion of the external water heated by a magma source sometimes fractures the country rocks so that causes explosive eruption, known as a phreatic eruption. If the steam expansion fractures the juvenile magma and erupts it out, the eruption is called as a phreatomagmatic eruption. Fine ash generated by phreatic/phreatomagmatic eruptions has smaller grain size than those generated by dry (without external water) eruptions.
Experiments of buoyancy-driven fluid-filled cracks as a model of a dike propagation by a magma ascent have revealed that the importance of the pressure inside the cracks. In contrast, the stress perturbation propagates at the shear wave velocity, which may become an upper limit of a fracture propagation. A sudden expansion of a steam from a point source may cause phreatic/preatomagmatic explosive eruptions, but the fracture mechanism has not yet understood well.
In this study, we visually observe a rapid crack propagation using the expansion of a pressurized air from a point source in transparent gels. We use three types of gels: (gel1) a hard quasi-Maxwell fluid with a shear modulus of $10^4$-$10^5$ Pa, (gel2) a soft quasi-Maxwell fluid with a shear modulus of $10^3$ Pa, and (gel3) a quasi-Voigt solid with a shear modulus of $10^2$ Pa. We introduce a pressurized air from the bottom of the gel, visually observed the pressure perturbation and the crack propagation by using polarized sheets, and record it by a high-speed video camera.
In gel1 and gel3, a thin air sheet with a sharp tip, usually recognized as a crack, propagates into the gel. On the other hand, in gel2, the air becomes a thick sheet with a round tip, which is more like a slug rather than a crack. In all experiments, the pressurized air erupts out the ash-like small particles generated by the friction between the pressurized air and the clack walls. The propagation velocity of the crack does not exceed the calculated shear wave velocity in gel1, but does in gel3. These results suggest that the combinations of the rheology and the gas pressure inside the cracks generate a variety in the shape of crack/slug and the fracture mechanism. The various shapes of the crack/slug may be observed as the difference of the resonance frequency by seismic signals.

キーワード：クラック、水蒸気爆発、ゲル
Keywords: crack, phreatic eruption, gel

 

# An experimental study of the role of subsurface plumbing on geothermal discharge

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In order to better understand the diverse discharge styles and eruption intervals observed at geothermal features, we performed three series of laboratory experiments with differing plumbing geometries. A single, straight conduit that connects a hot water bath (flask) to a vent (funnel) can originate geyser-like periodic eruptions, continuous discharge like a boiling spring, and fumarole-like steam discharge, depending on the conduit length and radius. The balance between the heat loss from the conduit walls and the heat supplied from the bottom determines whether and where water can condense which in turn controls discharge style. Next, we connected the conduit to a cold water reservoir through a branch, simulating the inflow from an external water source. Colder water located at a higher elevation than a branching point can flow into the conduit to stop the boiling in the flask, controlling the periodicity of the eruption. When an additional branch is connected to a second cold water reservoir, the two cold reservoirs can interact. Our experiments show that branching allows new processes to occur, such as recharge of colder water and escape of steam from side channels, leading to greater variation in discharge styles and eruption intervals. This model is consistent with the fact that eruption duration is not controlled by emptying reservoirs. We show how differences in plumbing geometries can explain various discharge styles and eruption intervals observed in El Tatio, Chile, and Yellowstone, USA.

キーワード：間欠泉、火道
Keywords: Geyser, plumbing system

# Experimental study on precursory pressure oscillation in the experimental geyser system

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Geysers exhibit characteristic behaviors such as precursory seismic events, time-predictability, and periodicity. They have similarities to volcanos in seismicity, so understanding the seismic events of geysers may provide potential insights into volcanic tremor. It is known that pressure pulses inside the water column of geysers trigger the tremor. However, the origin of the pressure pulses is still unclear. The phenomena of natural geysers are complicated and difficult to observe directly, so laboratory experiments may be useful to understand natural geyser system. In this study, we try to reveal the origin of the pressure oscillation inside the geysers using laboratory experiments.

We conducted two experiments: experiment 1 and experiment 2. In experiment 1, we used an analog experiment (basically same one documented by Toramaru and Maeda (2013)), which reproduces the natural geyser; the flask corresponds to the hot water chamber, the glass tube to the geyser conduit, the cooler water reservoir to the inflow of ground water and the hot plate to the geothermal heat.We measured pressure and temperature in the flask and took normal speed and high speed videos of the flask interior and the surface of water in a glass tube, thereby we examined the relationship between the phenomena taking place in the flask and the conduit, and the fluctuation of pressure. In experiment 2, in order to reproduce bubble formation caused by boiling, we designed an experimental setup which is capable of injecting air into the flask filled with water. Using this experimental setup, we measured pressure in the flask and took videos of behavior in the flask and at the surface of water to observe the pressure fluctuation like tremor, with varying experimental conditions such as injection amount (the amount of air injected into the flask), the injection rate (the amount of injected air par unit time), and initial water level (the level of water head in the conduit).

From the results of the experiment 1, it is found that (a) a bubble formation in the flask cause a pressure pulse and a subsequent damped pressure oscillation, (b) the amplitudes of the pressure pulses have positive correlation with the diameters of bubbles. From the results of the experiment 2, we find that (c) an air injection into the flask causes a pressure pulse and a damped pressure oscillation similar to result (a), (d) the pressure oscillations in the flask attenuate by the coupling with the fluctuation of water level in an opposite phase, (e) the amplitudes of pressure oscillations have positive correlations with the injection rate and initial water level, (f) the frequency of damped pressure oscillation has negative correlation with initial water level and no correlation with injection rate. Considering the result (a) and (c), it is suggested that the pressure oscillations are induced by additions of fluid (in this study, they are bubble formations by boiling and air injections) to the flask interior, and from the result (d), it seems that subsequent damped pressure oscillations are caused by the vertical movement of upper water column.

In conclusion, the pressure oscillations in the flask are induced by additions of fluid to the flask interior, and then attenuate by the coupling with the fluctuation of water level. Their amplitudes have positive correlation with the bubble diameters, injection rate and initial water level, and their frequencies has negative correlation with initial water level.

 

# Recent uplift of Iwo-yama volcano, Kirishima Volcanic Complex, southwest Japan, derived from ALOS-2 images

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Phreatic eruptions are usually smaller than magmatic eruptions, but they are sometimes a source of major hazards if infrastructures are close by. Here we report on rapid ground uplift in Iwo-yama volcano, one of vents in Kirishima Volcanic Complex, southwest Japan, potentiallly leading to a phreatic eruption.

Kirishima Volcanic Complex is a collection of volcanic vents striking northwest-southeast. Shinmoe-dake, one of the vents in the volcanic complex, had sub-Plinian and Vulcanian eruptions in early 2011. Iwo-yama is located about 6 km to the northwest of Shinmoe-dake. In Iwo-yama, elevated surface temperature has been observed since December 2015 and volcanic earthquakes and tremors have been observed in January and February 2016. With this background, we investigated the temporal evolution of the deformation in Iwo-yama volcano inferred from Synthetic Aperture Radar images taken from the ALOS-2 satellite.

We first generated interferograms all possible pairs of SAR images. Then we applied a time-series analysis to extract the temporal evolution of deformation of volcanic origin by removing errors due to the uncertainty of Digital Elevation Model and atmospheric disturbance. The time-series analysis reveals an uplift of a region with a diameter of about 500 meters. We found that the uplift started in late 2015 and amounts up to approximately 60 mm as of June 2016. The deformation pattern looks like almost a mirror of the subsidence observed in 1990s by JERS-1 images. These observations by JERS-1 and ALOS-2 suggest a depressurization in 1990s and a recent pressurization of the same aquifer located a few hundred meters beneath the surface. Electromagnetic observations also endorse the existence of the shallow acquire at the same depth level as we suggest. We need to note that the recent uplift continues even after a cessation of the volcanic earthquakes and tremors in late February 2016. This indicates that the observation of ground deformation adds insights into the current activity of a hydrothermal system that could lead to a phreatic eruption.

キーワード：合成開口レーダー、火山変動、水蒸気噴火
Keywords: Synthetic Aperture Radar, Volcano deformation, Phreatic eruption

 