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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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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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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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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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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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 ^oC. 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 ^oC. 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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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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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

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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.

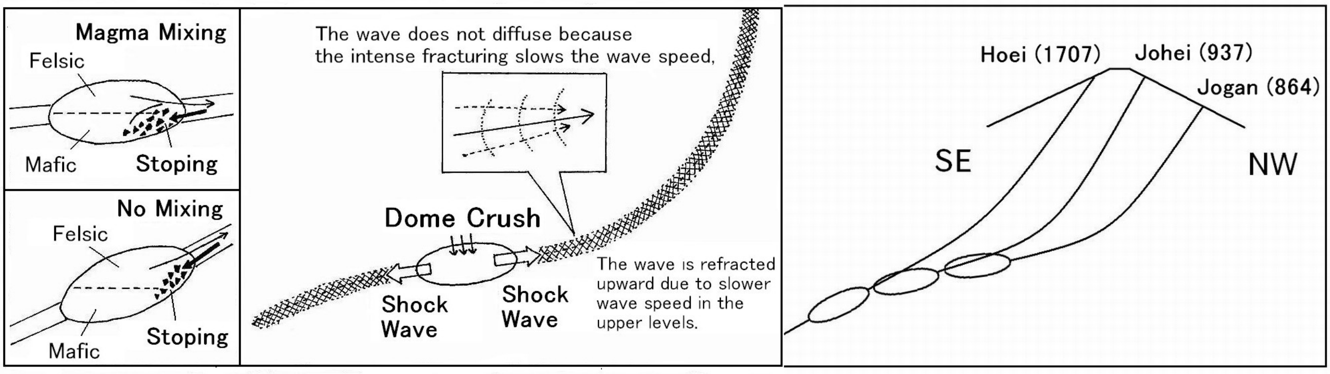
I propose to apply the model to the formation of the volcanic vent. The established theory explains that the eruption happens by pressure rise caused by boiling in the magma reservoir. The boiling, however, should stop when the pressure rises under the closed condition, and the explosive pressure rise 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