Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-01 Room:304 Time:May 24 16:15-16:30

A petrological test of the earthquake-trigger model of the Mt. Fuji Hoei eruption

ARUGA, Takafumi[1*] ; NAKAMURA, Michihiko[1] ; OKUMURA, Satoshi[1] ; YOSHIMOTO, Mitsuhiro[2]

[1]Department of Earth Science, Graduate School of Science, Tohoku University, [2]Mount Fuji Research Institute, Yamanashi Prefectural Government

It is fairly widely recognized that huge earthquakes may trigger volcanic eruptions. The statisitic validity of this “hypothesis” is, however, under debate. Besides, only little is understood about the triggering mechanisms and resulting incubation period from the earthquake to the eruption. The Hoei eruption of the Fuji volcano in 1707 A.D. occurred 49 days after the Hoei M 8.7 earthquake, and thus often referred as a typical example of the earthquake-triggered eruption. This clear paleographic record of the incubation period provides us an excellent opportunity to test the cause-and-effect link between the huge earthquake and magmatic eruption. Fujii (2002) proposed a triggering mechanism of the Hoei eruption, in which basaltic magma injected into the shallow dacitic magma chamber and induced volatile exsolution. In this study, we elucidate the timescale from magma injection to eruption from the mineralogical record in the Hoei erupted materials, and compare the result with the known interval of 49 days.

We found reverse zonings of plagioclase phenocrysts in the basaltic scoriae. The phenocrysts were considered to have been derived from the dacite magma because their core compositions are consistent with those in the silicic magma initially erupted in the Hoei sequence. Based on the measured MgO concentration profiles, we can estimate the timescale of magma mixing and then test the scenario that the Hoei eruption was triggered by the Hoei earthquake. The temperature of basaltic magma of the Hoei eruption was estimated to be 1080-1180 (Sato & Hara, 1990). With this temperature range, the timescales of magma mixing were calculated to be 45.9, 9.6 and 2.2 days at 1080, 1130 and 1180 ℃, respectively. Because these estimated timescales are shorter than 49 days, the mixing should have started after the Hoei earthquake. On the other hand, the estimated timescales are longer than the duration of the Hoei eruption, showing that the mixing was not syn-eruptive but preeruptive. These results support a model that the Hoei earthquake triggered the injection of basaltic magma into the shallow dacite magma chamber, leading to the Hoei eruption.

Keywords: Fuji Volcano, Hoei Eruption, Hoei Earthquake, Eruption Trigger, Tracer Element Diffusion

Japan Geoscience Union Meeting 2015
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SVC46-02 Room:304 Time:May 24 16:30-16:45

Evaluation of elastostatic effects of large earthquakes on the dike system around Mt. Fuji

HOSONO, Masaki[1*] ; MITSUI, Yuta[2] ; ISHIBASHI, Hidemi[2]

[1]Faculty of Science, Shizuoka University, [2]Institute of Geosciences, Shizuoka University

A recent study (Chesley et al., 2012) focused on mechanical effects of earthquakes on volcano systems, and calculated static stress change on the main dike of Mt. Fuji by the 1707 Hoei earthquake and the 1703 Genroku Kanto earthquake. In this study, we first performed validation tests of this previous study using my own codes, and confirmed that my calculation results and their results are the same. And then, we did the similar research calculating the normal stress perpendicular to the main dike and another dike that turned to be active after the 2011 Tohoku-oki earthquake. We examined the static stress changes on both dikes, by not only two earthquakes but nearby large earthquakes (the 762 Mino-Hida-Shinano earthquake, the 2011 Tohoku-oki earthquake, and possible Fujigawa-kako earthquake) as scenario earthquakes. The calculation results showed that the earthquakes having potentials to induce the eruption of Mt. Fuji were the Hoei earthquake and the Tohoku-oki earthquake, and the Fujigawa-kako earthquake. Moreover, we propose that the large earthquakes can be the switches of the dike activities beneath Mt. Fuji.

Keywords: Mt. Fuji, dike, large earthquakes, static stress changes

Japan Geoscience Union Meeting 2015
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SVC46-03 Room:304 Time:May 24 16:45-17:00

Magma ascent process during the late stage of Fuji 1707 eruption; constraints from plagioclase microlite

AMANO, Yamato[1*] ; ISHIBASHI, Hidemi[1] ; HOKANISHI, Natsumi[2] ; YASUDA, Atsushi[2]

[1]Guraduate School of Science, Shizuoka university, [2]Earthquake Research Institute, University of Tokyo

The Hoei eruption occurred at 1707 is the latest eruption of Fuji volcano. Plinian to sub-plinian eruption continued ca. 15 days with several times of pause during the eruptuin. Plinian and sub-plinian eruption of chemically homogeneous basaltic magma continued after the third days although dacitic-andesitic magma erupted in the early two days. At the end of the eruption, scoria cone was formed in the first crater, indicating transition of eruption style from plinian or sub-plinian to strombolian. However, the cause of this transition is not understood. In this study, textural and chemical analyses are done for plagioclase microlites in scoria samples collected from plinean fall deposit and the last scoria cone of Hoei eruption to clarify conduit ascent process in the late stage and the cause of the transition occurred at the end of the eruption.

Scoria samples of plinian and strombolian eruptions were collected from fall deposit located ca. 8km east from the source and from the scoria cone in the first crater. Among them, 30 scoria grains of the late stage continuous eruption called as Ho-IV stage, 5 grains for each of 6 units, and 4 strombolian scoria samples were investigated in terms of chemical composition, crystal size and crystal number density of plagioclase microlites. Chemical compositions of plagioclase microlites were analysed using EPMA (JEOL-8800R) at Earthquake Research Institute, University of Tokyo. Microlite size and number density were measured by image analyses of BSE images acquired by using SEM at Michibayashi Lab., Shizuoka University.

Both of plinian and strombolian scorias are aphyric with very trace amount of plagioclase and olivine phenocrysts rarely accompanied with pyroxenes. Maximum An number [=100Ca/(Ca+Na)], maximum size and crystal number density of plagioclase microlites are ca. 74.4, ca. 191μm, and ca. 1240 /mm^2 in the plinean scoria and ca. 78.3, ca. 293μm, and ca. 881/mm^2 in the strombolian scoria, respectively; maximum An number and maximum size are larger and crystal number density is lower for plagioclase micrlites in the strombolian scoria than those in plinean scoria.

Based on phase relation, eruption temperature was estimated to be ca. 1135 ℃. The pressure at which crystallization of plagioclase microlite started were estimated by using plagioclase-melt geohygrometer of Putirka (2008) to be ca. 21 MPa for plinian and ca. 24 MPa for strombolian eruptions, corresponding to depths of ca. 840-870m and ca. 940m, respectively. Conduit ascent velocities at the depths of microlite crystallization were estimated from number density of plagioclase microlites by using the MND water exsolution rate meter of Toramaru et al. (2008) to be ca. 54 km/h and 36 km/h for plinean and strombolian eruptions, respectively. The ascent velocity of plinian eruption was 1.5 times faster than that of strombolian eruption. Present results suggest that conduit ascent velocity decreased at the end of Hoei eruption, resulting in plinian-strombolian transition. The ascent velocity decrease was caused by phenomena occurred at depth $>$940m, such as decrease in conduit width and/or overpressure in magma reservoir.

Keywords: Fuji volcano, plagioclase, microlite, conduit ascent velocity, scoria, eruption style

Japan Geoscience Union Meeting 2015
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SVC46-04 Room:304 Time:May 24 17:00-17:15

Recycling of pyroclasts controls style of small basaltic explosion at Stromboli Volcano, Italy

MIWA, Takahiro[1*] ; KAWAGUCHI, Ryohei[1] ; NISHIMURA, Takeshi[2] ; AOYAMA, Hiroshi[3] ; YAMADA, Taishi[3] ; FUJITA, Eisuke[1]

[1]NIED, [2]Tohoku Univ, [3]Hokkaido Univ

Understandings of controlling mechanism on eruptive style is one of the most important subject not only for volcanology but also for hazard mitigation. Vesiculation, outgassing and crystallization that drive or break their ascent have been considered as essential factors for the controlling mechanism (e.g., Jaupart and Allegre, 1990; Houghton and Gonnerman, 2005). In contrast, recent studies have suggested that vigorous recycling of pyroclast into the vent occurs at basaltic volcano where small explosions are repeated (D'Oriano et al., 2014; Eychenne et al., 2014). The recycling of pyroclast that fills the vent can affect explosion dynamics such as shape and ejection speed of jet cloud (Goto et al., 2001; Ohba et al., 2002; Taddeucci et al., 2013).

This study examined component, texture, granulometry and chemical composition of ash samples from normal activity at Stromboli to discuss a controlling mechanism of explosion style of small basaltic explosion. Stromboli volcano has three vent regions as northeast (NE), central (C), and southwest (SW) craters. The three craters emitted white steam continuously that was interrupted by relatively strong explosion. During studied term (14:26-18:29, May 21th, 2014), different explosion styles were observed in each vents. The NE crater exhibited explosive emission of ash rich cloud, and the C and SW craters showed emission of glowing bomb with dilute ash cloud. We collected falling ash from the three craters every 4-18 minutes. Although the samples contain ash particles from the three craters, ash falling rate at sampling site becomes large after occurrence of ash rich explosion at NE crater. The ash particles are divided into Juvenile (glassy particle with elongate, spongy, or dense morphology), Recycled (non-glassy particles with highly crystalline which has similar texture with product of reheating experiment of basaltic ash; D'Oriano et al., 2013), Altered, and Crystal particles. The origin of the each type of particles are interpreted on the basis of their external and internal textures observed under stereoscopic and electron microscope (D'Oriano et al., 2014). We calculated bulk componentry using the componentry variations with grain size (125-250, 250-500, 500-1000, and 1000-2000μm) and grain size distribution. The bulk componentry shows that the volume fraction of recycled particles increases with ash falling rate at sampling site that concords the occurrence of ash rich explosion at NE crater.

The ash observation implies that burial of eruptive vent by recycled particles relates with occurrence of ash rich explosion at NE crater. The explosion occurs at which the gas rich magma from deeper conduit (e.g., Ripepe et al., 2001; Lautze and Houghton, 2007) reaches to the boundary between magma column and buried sediment. Emission of gas jet by the explosion blows the sediment which buries the vent-conduit (Patrick et al., 2007). Thick sediment can store large amounts of gas, magma and heat that generate ash rich cloud at the blowing. Therefore, we suggest that thickness of buried sediment is one of a controlling factor for the style of small basaltic explosion.

Keywords: eruptive style, recycling, basaltic magma, volcanic ash, Stromboli volcano

SVC46-05 Room:304 Time:May 24 17:15-17:30

Spatio-temporal changes of magma pressure in the conduit at Stromboli as inferred from analyses of tilt records

KAWAGUCHI, Ryohei[1*] ; NISHIMURA, Takeshi[2] ; AOYAMA, Hiroshi[3] ; YAMADA, Taishi[3] ; MIWA, Takahiro[1] ; FUJITA, Eisuke[1] ; GENCO, Riccardo[4] ; LACANNA, Giorgio[4] ; RIPEPE, Maurizio[4]

[1]NIED, [2]Science, Tohoku Univ., [3]Science, Hokkaido Univ., [4]Firenze Univ.

Recent geodetic observations at active volcanoes succeeded in detecting volcano deformations prior to a small volcanic explosion. These could be used for quantitatively understanding the magma ascent processes before eruptions. We installed three tilt meters and one broadband seismometer within a distance of 500 m from the active craters at Stromboli volcano, Italy, in the end of May 2014, and recorded large number of tilt data associated with explosions until September. In this study, we estimate the spatio-temporal changes of magma pressure in the conduit by using these tilt data.

We analyze tilts of 26 events recorded with high S/N ratio. These tilts at the three stations show uplifts toward craters from about 200 s before each explosion that is detected as an onset of seismic signal. By examining tilt vectors, we found that the tilt vectors roughly point to the direction of NE crater, and the direction of tilt vectors rotate about 5 seconds before the start of seismic signal. These characteristics are observed in the 22 events among 26 explosions.

To estimate the location of the source of tilt motions, we calculate the tilt motions due to pressure changes in an open conduit located at NE crater taking into account the topography of Stromboli volcano. The calculation results show that the directions of tilt vectors are changed by the difference in the depth of pressure source. We interpret that from few minutes to 5 seconds before an eruption magma pressure increases at the depth of about 50-100m below the crater. Then just before the eruption, the pressure source becomes deeper, down to about 150 m below the crater.

Keywords: Tilt motion, Strombolian eruption, Pressure source

Japan Geoscience Union Meeting 2015
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SVC46-06 Room:304 Time:May 24 17:30-17:45

Plinian eruptions without precursory basalt injection: Case study of the Sakurajima historic eruptions

ARAYA, Naoki[1*] ; NAKAMURA, Michihiko[1] ; OKUMURA, Satoshi[1]

[1]Department of Earth Science, Graduate School of Science, Tohoku University

Injection of new magma into a shallow differentiated magma chamber is often considered as a trigger of volcanic eruptions. This is primary based on the petrological observation that magma mixing precedes the eruptions by a short interval. However, some petrological records such as oscillatory zoning of phenocrysts, in addition to geophysical monitoring of active volcanoes (e.g. Iguchi et al., 2008), suggest that magma injections had occurred repeatedly without triggering eruptions immediately. In such a case, the mafic magma injection may be regarded as a preparation process for eruption rather than a trigger. To clarify the magma injection and accumulation processes prior to the past large eruptions is crucial for forecasting the volcanic activity. For this purpose, we investigated the pumice clasts of the three historic Plinian eruptions of the Sakurajima volcano, Kyusyu Japan in 1914-1915 (Taisho Era), 1779-1780 (Anei) and 1471-1476 (Bunmei). We have focused on compositional zoning of magnetite phenocrysts, because element diffusion in magnetite is relatively fast and thus has high time resolution.

The magnetite phenocrysts showed scarce compositional zoning in all the eruptions. This result indicates that the last magma injections occurred more than a few months before the eruptions. Hence, we infer that the magma injection did not trigger the historic eruptions immediately. This leads to an implication that a Plinian eruption may occur in the Sakurajima volcano without the injection of new magma prior to several months.

Keywords: Sakurajima Volcano, eruption trigger, magnetite, magma injection, magma mixing

Japan Geoscience Union Meeting 2015
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SVC46-07 Room:304 Time:May 24 17:45-18:00

Estimation of surface tension of lava from lava stalactite and lava stalagmite appeared in lava tube cave and tree mold

HONDA, Tsutomu[1*]

[1]NPO Vulcano-Speleological Society

[Introduction] Inside the lava cave and lava tree mold void formed by the basalt lava flow, lava stalactite and lava stalagmite are often observed. It is a phenomenon which the droplet of lava falls from a ceiling and deposits on the floor. The estimation of surface tension of lava from the pitch of lava stalactite and size of lava stalagmite appeared in lava tube cave and tree mold void are performed and compared with various lavas.

[Estimate of surface tension from lava stalactite] Lava stalactites are positioned periodically on the surface of the ceiling wall or side wall. From the periodical pitch of the stalactites, we can obtain the surface tension of the lava. The pitch will be critical wave length of the occurrence of instability of thin liquid film attached on the surface of the ceiling of the lava tube cave or lava tree mold void. The pitch P is shown as P=$2\pi(\gamma/g\rho_L)^{1/2}$, where$\gamma$is surface tension of liquid ρ_L is density of liquid, g is gravity acceleration. From the pitch of lava stalactites on the roof surface (P=3 to 4cm), the surface tension of lava γ=$P^2 g\rho_L$ /$4\pi^2$ was determined as 560~990 dyne/cm.

[Estimate of surface tension from lava stalagmite] After the droplet's falling either from the liquid layer of a ceiling or from a straw formed from a ceiling, the droplets of lava may be acumulated one after another on the floor. The cylindrical configuration of the lava droplet has a certain radius and length in such a way that the configuration of the droplets has almost the same size. It is thought that the surface tension of the droplet is playing an important role in this phenomenon. When it becomes impossible for surface tension to bear the weight of the droplet, the droplet will fall down. After that, again the liquid lava will be supplied, then, the droplet will repeat to fall down. Consequently many lava droplets will be deposited on a floor area. This phenomenon is very similar to the "weight of falling drops technique" which is the general method of measuring the surface tension of a liquid. Based on this idea, the study model for determining the surface tension $\gamma$of lava is made. When mass of the droplet is set to m, the force which pulls the droplet downward is f_1=mg (g is acceleration due to gravity), and the force of pulling up this upwards is f_2=$2\pi r\gamma$, where r is the radius of the lava droplet. The surface tension $\gamma$is calculable for f_1=$f_2$if the weight of the lava droplet is known. As f_1=mg=$\pi r^2 l\rho_L g$, where l is length of the lava droplet, ρ_L is the density of the lava, the surface tension γ=$rl\rho_L g/2$ can be obtained from r and l of the lava droplets accumulated on the floor. If we introduce ρ_L=2.5g/cm^3 and g= 980 cm/s^2, and by the fields observation of r and l, for example, the surface tension γ=490 dyne/cm can be obtained for r=0.2 cm, and l=2cm, and γ=980 dyne/cm can be obtained for r=0.25 cm, and l=4cm.

[Conclusions] The value of such surface tension obtained from the lava stalagmite is in good agreement with the surface tension acquired from the pitch of the waving of the liquid layer by the simple hydrodynamic instability model of gravity/surface tension acting on the melting liquid layer attached on the inner surface of the lava cave. This value also agrees well with the extrapolated value obtained by I. Yokoyama and S.Iizuka[1)] in the melting lava surface tension measurement experiments in Laboratory. As a conclusion, we could say that the surface tension plays a preponderant role for the lava stalactite and stalagmite formation in the lava cave and lava tree void. It seems that there is no significant difference between surface tensions of different basaltic lavas though further study for various lavas will be continued .

[References]

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Keywords: lava tube, volcanic cave, surface tension, lava tree mold

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Name of Volcano, Area	SiO_2 weight%(Reference), Eruption year	Cave or T-Mold	Measured P , r and ℓ	Estimated surface tension
Mt Fuji,Inusuzumi-yama, Mitsuike-ana	49.09%(H.Tsuya) , before 7000	Cave	P=3～4cm r=0.2~0.25cm,ℓ=2~4cm	560～990dyne/cm 490～980 dyne/cm
Izu-Osima, Mihara-yama	52~53%(T.Minakami), 1951	Cave	P= ～3cm	～560 dyne/cm
Shimane,Daikon-zima	47%(I.Sawa), before 190000	Cave	P= ～3cm	～560 dyne/cm
France, Reunion, Le Piton de la Fournaise	48.8~49.8% (N.Villeneuve),1998 48~50% (A.Peltier),2004	Cave	P=3～4cm r=0.2~0.25cm,ℓ=2~4cm	560～990 dyne/cm 490～980 dyne/cm
Vietnam, Central Plateau, Chupluk Volcano	48~52% (N.Hoang)	Cave	P=3～4cm	560～990 dyne/cm
Mt Fuji,Ken-marubi, Funatsu-tainai	50.88%(H.Tsuya), 937	T-Mold	P=3～4cm	560～990 dyne/cm
Mt Fuji,Ken-marubi, Yoshida-tainai	50.88%(H.Tsuya), 937	T-Mold	P=3～4cm	560～990 dyne/cm
Izu-Osima, Mihara-yama	52%(S.Nakano, T.Yamamoto), 1986	T-Mold	P=～4cm	～990 dyne/cm
Miyake-zima, O-yama	53~54%(T.Fujii et al),1983	T-Mold	r=0.1~0.25cm, ℓ=5cm	610～1530 dyne/cm
Hachijo-zima,Nishi-yama,	50.4~50.5%(M.Tsukui), Before 1100	T-Mold	P=3～4cm, r=0.2~0.25cm,ℓ=2~4cm	560～990 dyne/cm 490～980 dyne/cm
US,Oregon,Newberry Volcano, Lava cast forest	49～50%(J.Donnelly), Before 7000	T-Mold	P=3～5cm	560～1740 dyne/cm

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SVC46-08 Room:304 Time:May 25 09:00-09:15

Plinian eruption preceded by disruption of lava dome at Kelud volcano, Indonesia, in 2014

MAENO, Fukashi[1*] ; NAKADA, Setsuya[1] ; YOSHIMOTO, Mitsuhiro[2] ; SHIMANO, Taketo[3] ; HOKANISHI, Natsumi[1] ; AKHMAD, Zaennudin[4] ; IGUCHI, Masato[5]

[1]Earthquake Research Institute, University of Tokyo, [2]Mount Fuji Research Institute, Yamanashi Prefectural Government, [3]Graduate School of Environment and Disaster Research, Tokoha University, [4]Center for Volcanology and Geological Hazard Mitigation, Indonesia, [5]Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

Kelud volcano, Indonesia, is an active andesitic stratovolcano that has repeatedly erupted over many centuries. After a quiescent period since the dome-building eruption in 2007-2008, a plinian eruption with a radially spreading umbrella cloud at 18 km height occurred in February 2014. We present results of field observations, and discuss the sequence of this plinian event, with estimation of some physical parameters controlling eruption dynamics.

Eruptive deposits can be divided into three major units, Unit A to C, which corresponds to the main stages of this event. Unit A is pyroclastic density current deposits characterized by massive, poor-sorted, and composed of pumice, lithics and woods fragments. The distribution is limited to the northeastern side of the volcano, and extends up to ˜5 km from the summit. In distal area, this unit consists of a thin fine ash layer. Numerous trees blown down on the substrate in the northeast also belongs to the same unit. Unit B is pyroclastic fallout deposits. In proximal area, the unit is characterized by thick fallout deposits containing large pumice clasts and lava blocks. This unit underlies numerous ballistic ejecta originating from andesitic lava dome produced in 2007-2008. In distal area, the same unit is recognized as a thin ashfall layer. This unit is widely distributed from north to southwest. At Jogjakarta ˜200 km away, ˜2 cm ashfall was observed. This observation is consistent with satellite data showing the plinian plume drifted by strong easterly wind and dispersed mainly western side of the volcano. Unit C is poor-sorted, pumice-rich pyroclastic density current deposits that are distributed along southern and western valleys up to 3-4 km. Multiple, pumice-rich flow lobes are well developed. Large pumice clasts are generally concentrated in the upper part and flow front of the deposits. In the northern side, this unit is recognized as normally graded, fine ashfall layers. After the eruption, a number of secondary phreatic explosions occurred from the valley-filled pumice-rich deposits, and created explosion craters.

Volume of tephra fallout from all stages is estimated to be 0.32-0.46 km^3, using relationships between dispersal area and tephra thickness. A total volume of pyroclastic density current deposits for Stages 1 and 3 was estimated to be ˜0.1 km^3 based on the deposit distribution and thickness assumption. Duration of plume development was estimated to be 2.5-3 hours based on satellite images. From the tephra volume and eruption duration, mass discharge rate was calculated to be in the range 5.6?8.6$*10^7$ kg/s.

Our field observation suggests that, in Stage 1, pyroclastic density currents run at least 5 km to the northeastern side with blowing off vegetation including numerous trees. Perhaps, the 2007-2008 lava dome acted as a cap-rock of conduit, and it was partially destroyed from the northern edge. Initially, the eruption couldn't produce a buoyant steady column from an open conduit, but generated energetic and directed pyroclastic density currents (like a blast) from the partially disrupted dome. Then, the dome was completely destroyed and blown away by ascending magma, and the eruption entered the stable plinian phase, Stage 2. Within 3 hours, magma discharge rate decreased, and column collapse began. The eruption stage moved to Stage 3, when pumice-rich pyroclastic density currents occurred. They could run along valleys and buried them with multiple pumiceous flow lobes.

The plinian eruption in 2014 was characterized by a strong eruption plume preceded by blowing off lava dome and generation of energetic pyroclastic density currents. Also other pyroclastic density currents by column collapse followed the plinian eruption. Deposit data suggests that the scale of eruption is ranked as VEI 4 and one of the largest eruptions at Kelud volcano in the last few centuries.

Keywords: Kelud, Plinian, Lava dome, Pyroclastic density currents

SVC46-09 Room:304 Time:May 25 09:15-09:30

Pyrrhotite oxidation as an indicator of air entrainment into eruption columns and lava flows

MATSUMOTO, Keiko[1*] ; NAKAMURA, Michihiko[1]

[1]Department of Earth Science, Graduate School of Science, TOHOKU University

Air entrainment into eruption columns plays an important role for volcanic eruption dynamics as it causes buoyancy and temperature decrease for erupted materials. In this study, we develop a new method for quantifying the degree of air entrainment on the basis of Pyrrhotite (Po) oxidation reaction.

Since fO_2 of air is ca. 10 log units higher than that of the typical arc pre-eruptive magmas, oxidation of magmas may sensitively reflect the air entrainment. The oxidation reaction of Po proceeds quickly at high temperature within a several tens of seconds to a several tens of hours. Because this timescale corresponds to the typical eruption duration, the reaction may record the eruption dynamics. Matsumoto and Nakamura (2012) found Po crystals and their oxidized texture in the Sakurajima 1914-15 (Taisho) Plinian pumice clasts. In this study, we have additionally examined clastogenic lava (CL) (Yasui et al., 2007) and effusive lava (EL) samples of the Taisho eruption and estimated the Po oxidation conditions.

The oxidation products were identified as magnetite (Mt) and hematite (Hm) with reflective microscope and Raman spectroscopy. The Mt and Hm crystals were found to be Ti-free by using X-ray mapping except for the phenocrysts in the EL samples. The representative occurrence of Po and its oxidation texture were summarized as follows: In the pumice samples, unreacted Po was observed as well as relict Po with Mt-Hm composite reaction rims. In the CL, unreacted Po grains scarcely found and almost all the oxidation products were Hm. In the EL sample, unreacted Po, relict Po with Mt rim, Po pseudomorphs replaced entirely by Mt and Hm, and those by Hm existed. In contrast to the pumice clasts, no three-phase coexistence in a grain was found.

This occurrence of Po and oxides can be explained in terms of the 'achieved fO_2' and 'high-T and high- fO_2 duration'. The 'achieved fO_2' will be scaled by (A) pre-eruptive magma: $10^{-7.5}$?$10^{-9.0}$ bar, (B) equilibrium of Po and Mt: $10^{-6.9}$?$10^{-8.3}$ bar, (C) equilibrium of Mt and Hm: $10^{-4.7}$?$10^{-6.2}$ bar according to Matsumoto and Nakamura (2012), Huebner and Sato (1970) and Eugster and Wones (1962), and (D) the partial pressure of O_2 in air: $10^{-0.7}$ bar. Time scales of 'high-T and high- fO_2 duration' can be calculated by using (i) reaction duration for Mt rim of Po, (ii) reaction duration for Hm rim of Mt, and (iii) Ti diffusion time in Mt. Using these scales, occurrences of oxidation textures in each sample can be explained as follows: In the Plinian pumices, about half of the grains were not accompanied by oxides rim, showing that their achieved fO_2 were below (B); the rest of the grains having Hm rims experienced the fO_2 above (C). The grains between (B) and (C) rarely existed. The reaction duration of the pumices were estimated to be $<$3.5 hours (iii). The variation in the degree of oxidation reaction in the pumices can be interpreted to reflect the variation in the degree of contact with air and cooling process. The oxidation reaction of Po in CL occurred at fO_2 above (C) and was ceased in 6.3 to 22 hours (ii). The high fO_2 and relatively long reaction duration of CL is consistent with its origin; the CL magma was once fragmented, reacted with air and then welded and kept at high temperature. In EL, about half of the grains were unreacted at fO_2 below (B) and the rest grains were oxidized at fO_2 of (B) to (D). The estimated reaction duration for EL was 3.6 to 33 hours (iii). This fO_2 variation may be caused by partial fragmentation and welding with open system degassing or mixing with oxidized lava crusts. The systematic correlation between the Po oxidation reaction and the eruption processes suggests a possibility that Po oxidation can be an indicator of air entrainment into eruption columns and lava flows.

Keywords: oxidation, air entrainment, pyrrhotite, fO_2, Sakurajima

SVC46-10 Room:304 Time:May 25 09:30-09:45

Model of phreatic eruptions inferred from the 2014 eruption of Ontake Volcano

IDA, Yoshiaki[1*]

[1]Advance Soft Co.

A phreatic eruption (phreatic explosion) happened at Ontake Volcano on September 27, 2014 accompanied by more than 50 casualties including mountain climbers who were caught by volcanic smokes or hit by volcanic bombs. Phreatic eruptions often occur in many active volcanoes but what causes them is less understood compared with magmatic eruptions for some reasons as smaller scales and less influence to people. For that phreatic eruption of Ontake Volcano video images and deformation data that revealed basic natures of the eruption were obtained. Based on these data the present paper proposes a model that may be useful for a better understanding and simulation of eruptive processes.

A video camera at Takigoe Observation Point, Ministry of Land gave an interesting image about initial features of the Ontake eruption that began about 11: 55 a.m. even if the eruption point itself was obscured by clouds. In the summit area with weak fumaroles the eruption suddenly emitted voluminous dark gas, which first flowed down about 3 km long as a pyroclastic flow and then ascended as a plume. The plume reached the height up to 8 km above the sea level according to a radar measurement. Another video image taken from a helicopter about 2:00 p.m. showed that the plume was substantially weakened and split into several separate gas flows.

The gas that was emitted at an early stage of the eruption was very dark and moved down as a pyroclastic flow so that it should have contained abundant solid particles with a higher density than the air. Rich solid particles in the gas explain lots of volcanic bombs and thick ash deposits actually observed near the summit. The gas flow is understood to have turned to a plume when it deposited part of solid particles. It is likely that solid particles were generated by erosion of the permeable layer through which steam migrated to the surface and that resultant high permeability allowed the steam to flow violently out during the eruption.

The tilt data obtained at Tanohara Observation Point, Japan Meteorological Agency gives another important constraint on the eruption process. The data revealed that inflation first took place below the eruption point during about 7 minutes and then contraction followed as soon as the eruption started.

The inflation prior to the eruption was likely caused by increase of vapor in the underground water system. Simple vaporization, however, cannot produce inflation because successive vaporization is suppressed by pressure increase. Inflation often arises in volcanoes when some material ascends under gravity. Here, the process in which steam bubbles generated at the bottom ascend through the ground water is considered. The bubble formation may result from a thermal instability due to heat supply to the bottom consistently with no significant seismicity observed with the inflation.

The above idea gives a model of phreatic eruptions in the system of steam overlying ground water. The equilibrium described by an evaporation curve is assumed to hold at the interface between steam and water. The steam flux generated at the bottom of the ground water is prescribed as a function of time. The steam is assumed to migrate to the surface as a permeable flow and the effect of erosion is represented by the change of permeability whose speed is defined by a prescribed function of steam flux and permeability.

In this model pressure, permeability and gas fluxes are calculated as a function of time from a set of ordinary differential equations derived from conservation laws and thermodynamic relations. The differential equations give the solutions that qualitatively reproduce pre-eruptive underground inflation followed by rapid gas effusion during the eruption if constants and initial values of variables are suitably prescribed..

Keywords: phreatic eruption, phreatic explosion, Ontake Volcano, pyroclastic flow, crustal deformation, computer simulation

SVC46-11 Room:304 Time:May 25 09:45-10:00

A numerical study of pyroclastic flow dynamics: Development of a two-layer model based on Shallow-Water equations

SHIMIZU, Hiroyuki[1*] ; KOYAGUCHI, Takehiro[1] ; SUZUKI, Yujiro[1]

[1]Earthquake Research Institute, The University of Tokyo

Pyroclastic flows are density currents of mixtures of volcanic particles and gas that flow on the ground surface. They are characterized by wide ranges of density ratio ρ/ρ_a($\sim 10^0$-10^3), where ρ and ρ_a are the densities of current and ambient, respectively. The dynamics of pyroclastic flows are affected by many physical factors such as settling of particles and entrainment of ambient air. In order to understand these effects on the dynamics of pyroclastic flows with wide ranges of ρ/ρ_a, we have developed a new numerical model based on shallow-water equations. The model has been verified by applying it to the dam-break problem, for which analytical solutions of different fluid dynamical stages are available.

In order to calculate the dynamics of pyroclastic flows with wide ranges of ρ/ρ_a using the shallow-water equations, the balance between the driving force and the dynamic reaction at the flow front (i.e., front condition) should be correctly taken into account. In previous works, two types of numerical models have been proposed to express the front condition: Boundary-Condition (BC) type model and Artificial-Bed (AB) type model. BC type model is a numerical method in which the front condition is applied to the boundary condition at the flow front. In AB type model, the front condition is calculated by setting a thin artificial bed ahead of the front. We have revealed that AB type model is applicable to the currents of $\rho/\rho_a \geq 100$, whereas BC type model should be used for the currents of $\rho/\rho_a \leq 100$. We have also developed a rigorous algorithm calculating the front condition using BC type model.

Our numerical method enables us to investigate the effects of the settling of particles and the entrainment of ambient air on the flow dynamics for wide ranges of ρ/ρ_a. Particle settling decelerates the front speed and enhances the formation of "jump" that separates the current into head and tail parts. Entrainment of ambient air also decelerates the front speed and suppresses the formation of the jump between the head and the tail of the current. Our results also suggested that the rate of entrainment tends to increase as ρ/ρ_a increases. When both the effects of particle settling and entrainment are present, the competition between these two effects is considered to result in diverse flow patterns.

Pyroclastic flows with large density gradients are generally divided into a dilute overriding part ($10^0 \leq \rho/\rho_a \leq 10^1$) and a dense basal part ($\rho/\rho_a \sim 10^3$). In order to simulate the dynamics of such realistic pyroclastic flows, we have developed a two-layer model where the dynamics of the dilute overriding part is solved by BC type model and that of the dense basal part is solved by AB type model. In the dilute overriding part, the effects of the settling of particles and the entrainment of ambient air are taken into account. In the dense basal part, the effects of the settling of particles and the basal friction are taken into account. We present some preliminary results showing temporal evolutions of the dilute overriding part, the dense basal part and the deposits.

Keywords: pyroclastic flows, density currents, gravity currents, Shallow-Water equations, two-layer model

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-12 Room:304 Time:May 25 10:00-10:15

Effects of vertical diffusivity and plume shape on the inversion analysis of tephra fallout deposits

KIYOSUGI, Koji[1*] ; KOYAGUCHI, Takehiro[1] ; SUZUKI, Yujiro[1]

[1]Earthquake Research Institute,The University of Tokyo

Estimation of volcanic plume condition from fallout deposits is an important volcanological subject; such estimations are indispensable for reconstruction of the dynamics of volcanic plumes in the past as well as forecast of tephra fallout distribution during ongoing eruptions. The goal of this study is to develop an accurate inversion method to estimate tephra source parameters (location, height, amount and grain size of tephra) from distribution of tephra fallout deposits. In previous studies on the inversion analyses using tephra fall deposits (e.g., Klawonn et al., 2012; Mannen 2014), vertical diffusivity of particles and bending of volcanic plume due to wind are sometimes assumed to be negligible. In this study, we investigated the applicability of these assumptions through systematic advection-diffusion simulations of single-sized tephra particles released from point sources above a vent.

In the advection-diffusion simulation of single-sized particles from a point source, the released particles diffuse and form a "particle cloud". If the vertical diffusivity of particles is ignored, particle clouds diffuse only horizontally and the distribution of particles is described by a bivariate Gaussian distribution (BGD). On the other hand, when the vertical diffusion exists, the particle cloud has an oblate spheroid shape. Because of the presence of wind, the vertically extending particle cloud keeps its horizontal movement after the landing of its bottom until the settlement of its top. As a result, the distribution of deposits deviates from a BGD in three ways: (1) increase of the kurtosis in the cross wind direction, (2) increase of the skewness and (3) increase of the variance along the wind direction. Among these deviations, (1) and (2) are caused by vertical diffusion of particles during deposition of the particle cloud and become significant when $(D_z/v_t z)^{1/2} \geq 0.2$ where D_z is the vertical diffusion coefficient, v_t is the terminal velocity, z is the source height. The deviation (3) is caused by horizontal movement of the particle cloud in the wind direction during the deposition and becomes significant when $D_z^{1/2} D_h^{-1/2} W v_t^{-1} \geq 3$ where W is the wind velocity, D_h is the horizontal diffusion coefficient.

Volcanic plumes generally bent to leeward when wind is present. The effect of bending plumes on the distribution of tephra fallout deposits is evaluated through comparison between the bending distance of the plumes and the advection distance of settling particles. Dimension analysis and wind-affected volcanic plume models (e.g., BENT; Bursik 2001) suggest that the trajectory (bending distance x and height z) of a bending weak plume is approximated by $z=CB^{1/3}W^{-1}x^{2/3}$ (Wright 1971), where C is a constant, B is the effective buoyancy flux (Sparks et al., 1997). On the other hand, the advection distance of particles can be calculated as $b=zW/v_t$. If the bending distance x is as large as the particle advection distance b (i.e., $x/b \geq n$; n is a constant of order 10^{-1}), the effect of bending plumes cannot be ignored; on the basis of the equations of bending distance and advection distance, this condition can be rewritten as $C^{-3}B^{-1}zWv_t^{2} \geq n^2$.

The above results show that the effect of vertical diffusivity is significant when finer particles are released from lower altitudes. In contrast, the effect of bending plume is significant when coarser particles are released from higher altitudes. The results also suggest that both the effects can be insignificant for particles with intermediate grain size. From the above equations, it is inferred that the terminal velocity of such particles with intermediate grain size ranges $D_z/0.04z \leq v_t \leq nC^{3/2}B^{1/2}z^{-1/2}W^{-1/2}$ when $Wz(D_zD_h)^{-1/2}<75$ and $WD_z^{1/2}/3D_h^{1/2} \leq v_t \leq nC^{3/2}B^{1/2}z^{-1/2}W^{-1/2}$ when $Wz(D_zD_h)^{-1/2}>75$. These relationships between grain size and particle distribution must be taken into consideration in the inversion analysis.

Keywords: volcanic plume, tephra fallout deposits, advection-diffusion model, inversion analysis

SVC46-13 Room:304 Time:May 25 10:15-10:30

A trial of measurement for shape and velocity of ash-fall by using a digital image analysis technique

HATTORI, Yasuo[1*] ; NAKAO, Keisuke[1] ; SUTO, Hitoshi[1]

[1]Central Research Institute of Electric Power Industry

Accurate descriptions of terminal velocity of ash-fall are practical interest in volcanic ash risk assessment on critical infrastructure (e.g. Wardman et al. 2012). Numerical simulations with an ash transport- and deposition-model, which has a capability to estimate spatial- and temporal-distributions of ash concentration and deposition, have become a powerful tool of the risk assessment (e.g. Folch 2012). Such simulations give the solution of governing equations on ash transport processes with numerical procedures. The governing equations include some empirical formulas with assumptions. Also for the estimation of terminal velocity of ash-fall, many empirical formulas have been already reported, but there exists considerable scattering of calculations among them (e.g Folch 2012).

In the present study, we examined a measurement for shape and velocity of ash-fall by employing a digital image analysis technique. We configured the experimental setup based on a shadowgraph particle measurement system of Dantec Dynamics to deal with non-spherical particles. The particles were illuminated by high-intensity pulsed lasers, Nd: YAG laser, with an optical diffuser. A CCD camera was placed in front of the light source, and the camera was equipped with a long-distance microscope lens to obtain visualized images of small particles. We carried out a trial measurement for sedimentation of corrected ash and discussed the optimization of measurement parameters and relationship between shape and velocity of ash-fall in a laboratory test. More details will be presented in the presentation, and we believe that our study must be helpful to develop the numerical simulations for evaluation of volcanic ash risk.

The authors wish to express our gratitude to Mr. Y. Futawatari of Dantec Dynamics, Ltd., Mr. T. Sato and Mr. K. Ota for helpful comments on the design of the optical setup, and to Mr. K. Toshida, Dr. D. Miura and Dr. S. Takeuchi for fruitful discussions on this study.

Keywords: Terminal fall velocity, Particle image velocimetry, Laboratory test, Ash transport- and deposition-model

Japan Geoscience Union Meeting 2015
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SVC46-14 Room:304 Time:May 25 11:00-11:25

Stokes–DEM coupled simulation for a granular media of magma chamber

FURUICHI, Mikito[1*] ; NISHIURA, Daisuke[1]

[1]Department of Mathematical Science and Advanced Technology, Japan Agency for Marine-Earth Science an

The dynamics of a granular media has been suggested to play an important role in a reheated magma chamber by a hot intrusion (e.g. Burgisser and Bergantz, 2011). Although several mechanisms, such as Rayleigh Taylor instability, unzipping, and rhythmic convection (e.g. Shibano et.al. 2012, 2013) have been proposed for characterizing an evolution of crystalline magma chamber, their contributions in the long geodynamical time scale are not clear yet. Thus we performed dynamical numerical simulations of the granular material in three dimensions to investigate the thermal evolution of the magma chamber.

In order to solve high-viscosity fluid and particle dynamics for modelling a melt–crystal jammed state of the magma, we have developed a coupled Stokes–DEM simulation code with two key techniques: formulation of particle motion without inertia and semi-implicit treatment of particle motion in the fluid equation (Furuichi and Nishiura, G-cubed, 2014). Our simulation can successfully handle sinking particles in a high-viscosity fluid.

In our simulation, the top fluid–particle jammed layer is heated by the hot basal fluid at the bottom. This initial setting represents the first-stage toy model for an erosion process at a melting roof of the magma chamber. We have investigated the dynamical patterns of the settling particles which strongly depend on the rheology of the granular layer. In addition, we have also examined the dynamical role of the density of the basal hot melt. Our numerical result indicates the possibility of the spontaneous formulation of crystal rich layer on the basal dense melt layer.

Keywords: Magma chamber, Viscous granular material, Magmatic dyamics, Reactivation, Discrete element method, Stokes flow

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-15 Room:304 Time:May 25 11:25-11:50

Forecasting the transition of explosive volcanic eruptions using a combined model for conduit flow and eruption column

KOYAGUCHI, Takehiro[1*] ; SUZUKI, Yujiro[1]

[1]Earthquake Research Institute, The University of Tokyo

We have developed a combined model for one-dimensional (1D) conduit flow and three-dimensional (3D) eruption column dynamics in order to forecast the transition of explosive volcanic eruptions.

During explosive eruptions, the ascending velocity of magma typically reaches the sound velocity of the gas-pyroclast mixture at the crater base. In this case, the motion of magma from the magma chamber to the eruption cloud is divided into the following three regions: conduit flow from the magma chamber to the crater base (Region 1), decompression and compression processes inside the crater (Region 2), and eruption column dynamics in the atmosphere (Region 3). According to the approximate solution of the 1D conduit flow model (Koyaguchi, 2005), the flow rate in Region 1 depends mainly on magma-chamber pressure, magmatic properties (e.g., temperature, water content and viscosity), conduit radius and conduit length from the magma chamber to the crater base. The decompression/compression process in Region 2 is essentially controlled by crater geometry; when the depth of crater and the ratio of the cross-sectional areas at the top and the base of the crater are given, exit pressure and exit velocity at the crater top are estimated as a function of flow rate (Koyaguchi et al., 2010). When the exit pressure differs from the atmospheric pressure just above the crater, the fluid dynamical features of the eruption column (i.e., Region 3) are significantly affected by the decompression and/or compression processes just above the crater; the ejected material accelerates or decelerates owing to decompression or compression into the atmosphere. According to 1D steady eruption column dynamics models (e.g., Woods, 1988), the column dynamics after the pressure of the eruption column balances the atmospheric pressure depends on magmatic properties, magma discharge rate, and ascent velocity at the time when the pressure of the eruption column balances the atmospheric pressure just above the crater top. The above consideration suggests that the evolution of conduit-crater geometry as well as that of chamber pressure plays a key role in the transition of explosive eruptions.

In this study, in order to evaluate the effects of conduit-crater geometry on the transition of explosive eruptions, we have derived an approximate solution to calculate the velocity and pressure at the crater top as a function of parameters on crater geometry, and systematically investigate the effects of over- and under-pressure at the crater top on the column dynamics using a 3D column dynamics model (Suzuki et al., 2005). The overall features of column dynamics such as column collapse condition in the 3D simulations are qualitatively consistent with the results based on the combination of the 1D column dynamics model and the 1D decompression/compression model (e.g., Woods and Bower, 1995; Koyaguchi et al., 2010). The 3D simulation results also show some distinct features that cannot be expressed in the 1D models; the over- or under-pressured jets are characterized by the highly accelerated annular supersonic flow with the central subsonic flow above the normal shock. Such velocity structure causes partial collapse and/or oscillation of the eruption column. We propose a regime map showing the diverse flow patterns of eruption columns in the parameter space of the flow rate and the crater geometry, and discuss how the flow patterns of eruption columns change as chamber pressure and conduit-crater geometry evolve in the course of typical explosive eruptions.

Keywords: conduit flow, eruption column, numerical model, transition of eruption style

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-16 Room:304 Time:May 25 11:50-12:05

MP radar observation of the explosive eruption of Sakurajima on May 10th, 2014

SATO, Eiichi[1*] ; FUKUI, Keiichi[1] ; SHIMBORI, Toshiki[1] ; ISHII, Kensuke[1] ; TAKAGI, Akimichi[1] ; YAMAUCHI, Hiroshi[1] ; MAKI, Masayuki[2]

[1]Meteorological Research Institute, [2]Kagoshima University

Although it has been recognized that volcanic ash clouds can be captured by weather radars from the late 1960s, the technique to estimate the amount of pyroclastic materials is not established now. On the other hand, MP (polarimetric) weather radar techniques have been rapidly developed in the field of Quantitative Precipitation Estimation (QPE) and Hydrometeor Classification (HC). We are now trying to develope Quantitative Ash Estimation (QAE) techniques by MP radar, however, false echo is one of the obstacles of QAE.

In this research, we tested a method of determination of false echo region by correlation coefficient (ρhv), which represents non-homogeneity of meteorological clutters, to the case of explosive eruption of Sakuraijma on May 10th, 2014. Then, we analyzed frequency distributions of polarimetric parameters in the volcanic plume regions and the false echo regions. As a result, it is considered that the false echo region depended on multiple factors.

Keywords: volcanic plume, MP radar, polarimetric radar, false echo

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SVC46-17 Room:304 Time:May 25 12:05-12:20

Observations of Sakurajima Volcanic Ash Column with X-band Polarimetric Radar and Ka-band Doppler Radar

MAKI, Masayuki[1*] ; MAESAKA, Takeshi[2] ; TANADA, Toshikazu[2]

[1]Research and Education Center for Natural Hazards, Kagoshima University, [2]National Research Institute for Science and Disaster Prevention

X-band polarimetric radar and Ka-band Doppler radar data from two explosive eruptions of Sakurajima volcano were analyzed to reveal the inner structures of their respective volcanic ash columns. The first case analyzed was the eruption that occurred on August 18, 2013. The ash column height during that event was 5.5 km above the crater, and falling ash hindered surface traffic visibility in the downtown area of Kagoshima City, which is located about 13km west of the Showa crater. A linear interpolation in time and space was applied to the X-band polarimetric radar data, with 5-minute intervals and 12-tilt elevation angles, to construct a three-dimensional distribution of the radar parameters with a one minute interval and a 250m spatial resolution. The three-dimensional distribution of reflectivity in the ash column reveals a non-uniform structure; the ash column consists of several reflectivity cores which correspond to individual explosions. The pyroclastic material ascent speed, detected from Doppler velocity analysis, was about 60 ms-1 just above the crater. Analyses of reflectivity, differential reflectivity, and co-polar correlation coefficient suggest that the uniformity of ash particle size distribution and particle shape proceeds due to a size sorting mechanism in the ash column when it is moving in a down-wind direction. In the second eruption analyzed, which occurred on May 10, 2014, the ash column reached a height of 4500m above the crater. This eruption was observed by a Ka-band research Doppler radar, set up 3.6km from the crater, and an X-band operational polarimetric radar. RHI scanning of the ash column with the Ka-band radar showed it to have a fine kinematic structure.

Keywords: Weather radar, Ka-band radar, volcanic ash column, reflectivity, Doppler velocity, size sorting