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The history of volcanic eruption based on widespread tephra correlation at Pliocene and early Pleistocene in Japan

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The frequency and the scale of the large volcanic eruption in the Japanese Islands are one of the important problems in the forecast of the long-term geological features change. The restoration of the history of the large volcanic eruption in the late Pleistocene has been examined by the correlation with the pyroclastic flow deposit and the distal fine ash (For example, the Ito pyroclastic flow deposit and the comparison with the AT volcanic ash of 30ka: Machida, Arai, and 1974, etc). The eruption of VEI 6 was generated eight times and the VEI 7 was generated nine times for the past 125,000 years (Machida, Arai, and 2003). It is clarified that the extremely large volcanic eruption in the Japanese Islands is the frequency once about 7000-8000 year. However, an older age, the volcanic edifice and geographical features in the caldera etc. disappear, a lot of source volcano cannot be specified, and the evaluation at the scale and age of a volcanic eruption are difficult.

In tephrochronology, identification and the comparison of the tephra based on the chemical composition analysis of mayor element (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P) of the volcanic glass from the 1990's. As a result, the comparison accuracy of an older pyroclastic flow deposit and the tephra in the remote place improves. The Ebs-Fukuda tephra (1.75Ma: Yoshikawa et al., 1996) and the Omn-Sk110 tephra (1.65Ma: Nagahashi, 1998), etc. were found. It has come to obtain information on the large volcanic eruption the widespread tephra correlation before early Pleistocene. Moreover, Kikkawa (1990) showed that trace element such as La, Ba, Sr, and Y was identified from the difference of the element characteristic even by the tephra to which the major elemental composition of the volcanic glass was similar. In addition, Mizuno (2001) showed that the source volcano area of the widespread tephra was definable to Chubu Sangaku, Kyushu, and Tohoku region from the element characteristic of a trace element of volcanic glass of the pyroclastic flow deposit to some degree. We do trace elemental chemical composition analyses of the volcanic glass of the index tephra in around 2000, and have been examining the comparison and tephrochronology of the index tephra of central Japan based on the characteristic. It has reported on a petrology feature, the eruption scale, the source and the age of the tephra about 36 widespread tephra layers of 5Ma-1Ma that did trace analyses.

Among 36 tephra layers, Tohoku type (La/Y : $<$0.5, Ba/La $>$30) are eight tephra layers, i.e. the In1-B25 tephra (3.1Ma : Tamura et al., 2014), the TmgR4-HSC tephra (2Ma : Shimogama and Suzuki, 2006), the Kry1-HAS tephra (1.9Ma : Tamura et al., 2006), the Kd44-Nk tephra (1.9Ma : Nakayama and Suzuki, 2007 ; Tamura et al., 2008), the Kumado-Kd22Utephra (Murata and Suzuki, 2011), the Akai-Kd18 tephra(Murata and Suzuki, 2011), the Ashino-Kd8-CH13 tephra (1.3Ma : Murata and Suzuki, 2011 ; Tamura et al.) and the Ysm-CH3 tephra (1Ma : Tamura et al). It concentrates on 2Ma-1Ma. Tephra layers presumed to be a Kyushu origin are the Hbt1-MT2 tephra (2.8-2.9Ma: Tomita, Kurokawa, 1999), the Ass-Tmd2 tephra (2.6Ma : Tamura et al., 2008), the Skt-Kd16 tephra (1.4Ma: Mizuno, 2007), and the Ss-Pnk tephra (1.02Ma: Machida and Arai, 2003). As for the Trb1-Ya4 tephra (4.2Ma: Tamura and Yamazaki, 2004) and the Ksg-An77 tephra (4Ma: Tamura and Yamazaki, 2004) have the possibility of the Ryohaku mountain origin from the grain degree tendency to the tephra particle. Tephra layers of the Chubu Sangaku origin are 20 layers. The tephra of the Chubu Sangaku origin begins to appear because of Hgs-An129 tephra (Satoguchi and Nagahashi, 2012) of about 3.6Ma. Moreover, it concentrates between 3Ma-1.5Ma with 16 tephras.

The Tohoku origin tephra layers are concentrated on 2Ma-1Ma and the Chubu Sangaku origin tephra concentrates on 3Ma-1.5Ma.

Keywords: Widespread tephra correlation, Pliocene, early Pleistocene, Histoly of volcanic eruption, Japanese Islands

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Emplacement processes of Takayubaru lava flow which actived before Aso-4 pyroclastic flow

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Eruption of Omine volcano and effusion of associated Takayubaru lava, just before large-scale Aso-4 pyroclastic eruption, formed a pyroclastic cone 200 m high, and lava plateau of block lava with ca. 100 m thickness and an area of 28 km^2. Both Aso-4 pumice and Takayubaru lava are dacite in composition and are similar, however, the former made an explosive eruption, whereas, the latter, an effusive eruption.

We made a cross section of Takayubaru lava plateau, using the drill-core data of Kumamoto Office of River and National Highway (1994). We found that the basement is inclined from the base of Omine cone (200 m in elevation) toward 3 km west (15 m in elevation), where depression occurs. The thickness of Takayubaru lava becomes maximum of 140 m at the depression, and decreases toward further west to become minimum of 10 m at the western end. The surface of lava is nearly flat. The N-S crossed section shows that the land surface is inclined toward south. The southern end is 50 to 100 m lower than the northern end, after 3.5 km in distance. This tilt was supposedly caused by Futagawa active fault.

The drilling core include, from the top to bottom, soil, Aso-4 tephra, (no soil), upper auto-brecciated part of lava (15 m thick in the middle part), massive part of lava (80 m thick), and lower auto-brecciated part of lava (2 m thick), which were underlain by Futa Formation.

Massive part is homogeneous, and has no interstitial auto-brecciated part. Modal composition of phenocryst minerals does not show much difference from top to bottom. Vesicles are observed in all positions at the fore front of lava flow, however, they are only observed in the upper and bottom part of the lava from the middle and near-source area. Silica content of bulk lava from all position varies within 2 wt.%. It is especially homogeneous ($<$1 wt.% SiO_2) in the middle massive part. Plagioclase crystals show lineation. The standard deviation in angle does not change from top to bottom. Plagioclase crystals show characteristic honey-comb texture, or melting texture. The degree of melting is greater at the upper portion. All these observations strongly suggest that Takayubaru lava flow does not represent multiple flows but a single flow unit.

We estimated lava effusion rate from the equation relating single lava flow length (L) and effusion rate (E), i.e. L=10ˆ3.11∗Eˆ0.47 (Calvari & Pinkerton, 1998). The length of Takayubaru lava flow, 7.5 km gives the effusion rate of 42 m^3/s. Because the volume of Takayubaru lava flow is 2.0 km^3, the period of flowing event was calculated to be 1.4 year. If we assume a constant rate of flow, then the velocity was ca. 0.6 m/hr.

Keywords: Aso, Omine volcano, Takayubaru lava flow, Effusion rate

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The occurrence and grain-size characteristics of distal facies of Aso-4 ignimbrite in Yamaguchi Prefecture

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Aso-4T ignimbrite is a low-aspect ratio ignimbrite which distributed widespread from Aso caldera via Seto Inland Sea to Yamaguchi Prefecture. Though the mechanisms of transportation and deposition of that are important issue of volcanology, the fundamental data such as the depositional distribution and grain-size characteristics were not studied enough. Then we surveyed geologically and analyzed the grain-size of Aso-4T ignimbrite in Yamaguchi Prefecture in addition to Aso-4A ignimbrite and Aso-4 ash-fall in the other localities for its comparison.

Aso-4T ignimbrite distributes widespread in central to western region of Yamaguchi Prefecture with relatively thin (2-3 m) thickness in contrast with Aso-4A ignimbrite which fills valley to a thickness of more than 40 m in Oita Prefecture. Aso-4 ash-fall deposits as 15 cm-thick and partially modified by water current and resedimented at Miyoshi city in Tokushima Prefecture.

Aso-4T ignimbrite is significantly altered and rich in clay. Oppositely, Aso-4A ignimbrite is coarse, poorly sorted and includes small amount of clay. Aso-4 ash is fine , relatively sorted and rich in clay. The maximum size of pumice in Aso-4T at 130-160 km from the source caldera is 1.0 to 1.2 cm, that in Aso-4A at 50-70 km is 20-30 cm and that in Aso-4 ash-fall at 314 km is 5 mm. The maximum length of hornblende in Aso-4T at 50 km and 130-160 km is 3.8 mm and 2.8-3.1 mm. That in Aso-4A at 50 km is 3.4 mm and in Aso-4 ash-fall at 314 km and 680 km is 2.5 mm and 0.9 mm.

The aspect ratio of hornblende in Aso-4T is 1.6-8.0, that in Aso-4A at 50-70 km is 1.5-8.0 and that in Aso-4 ash-fall at 314-682 km is 1.0-6.0.

Hornblende is resistant to alteration so that it suites to the study of grain-size characteristics of significantly altered ignimbrite such as Aso-4T. We recognized the tendency of the grain-size characteristics as follows:

1) the grain-size of hornblende in Aso-4A ignimbrite is slightly larger than that in Aso-4T ignimbrite

2) longitudinal variations of maximum size of hornblende in Aso-4A and 4T ignimbrites are relatively homogeneous than that in Aso-4 ash-fall

3) aspect ratios of hornblende in both ignimbrites are high than that in Aso-4 ash-fall.

Keywords: Aso-4 ignimbrite, Yamaguchi Prefecture, grain-size characteristics

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Geological Map pf Kuju Volcano; More accurate eruptive history and magma eruption rate

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Geological Survey of Japan, AIST has published a new Kuju volcano geological map. In this "Geological Map of Kuju Volcano", we re-examined the stratigraphy of Kuju volcano by tephra study and many K-Ar and ^{14}C dating. Kuju volcano is composed of an aggregation of small stratovolcanoes and lava domes of dacite from basaltic andesite. Approximately old volcanic body exists in the west, new volcanic body are distributed to the east. Around the Kuju volcano, there are volcanic fan made of block and ash flow deposits, debris avalanche deposits and debris flow deposits. Large-scale pyroclastic flows, such as the Handa pyroclastic flow deposits, also distributed around Kuju volcano. We divided the activity of Kuju volcano into four stages, the 1st stage (from 200ka to 54ka), the 2nd stage of the Handa pyroclastic flow eruption occurred (54ka), the 3rd stage (from 54ka to 15ka) mainly occurred at the central area of Kuju volcano, the 4th stage (from 15ka to present), characterized by eruption of mafic magma. For the fourth stage, we performed a detailed tephra description including a relatively small (magma) steam eruption. We were re-examined the magma eruption rate of the 3rd and the 4th stage. The magma eruption rate of the 4th stage is about 0.45km^3/1000 years (DRE) and has increased from the 3rd stage of about 0.29km^3/1000 years.

Keywords: active volcano, Kuju volcano, eruptive history, geological map of volcano, eruption rate, dating

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Volcanic History of Ogasawara Ioto (Iwo-jima)

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Ioto (Iwo-Jima; Sulphur Island) is a volcanic island located at the volcanic front of the south end of Izu-Bonin arc. The island consists of a central cone and southwest rim of a submarine caldera with a diameter of about 10 km. High rates of geothermal activity and crustal uplift have been observed, which are considered to be related to magma intruding at a shallow depth. Therefore, Ioto volcano is considered to be an active resurgent dome. However, eruptive history, including the process and timing of caldera formation, has not been clarified. Eruptive history based on our recent field survey, dating, and chemical analysis is as follows. A pre-caldera edifice was formed by volcanic activity of trachyandesite-trachyte magma in a subaerial and subaqueous environment. The K-Ar ages of the lavas on the Western rim represents about 0.07-0.08 Ma, but these results have large error. The magma composition and types of eruption were similar to those of the post-caldera edifice. It is still unclear when the caldera was formed. The caldera floor, which was a sedimentary basin with shallow marine sediments and a subaqueous lava flow, has been present at least since 2.7 kBP. Furthermore, a small volcanic island covered with trees used to exist in the Motoyama area. The complicated sequence of the Motoyama 2.7 kBP eruption is described as follows. First, on the volcanic island or in the surrounding shallow water, an explosive phreatomagmatic eruption occurred that formed subaqueous welded tuff (Hinodehama ignimbrite) and a subsequent thick subaqueous lava flow (Motoyama lava). While the Motoyama lava was still hot, the eastern part collapsed. The collapsed mass was quenched to form large blocks similar to pillow lava. A subsequent large phreatomagmatic eruption occurred, destroying the hot Motoyama lava, the older edifice, and the marine sediment. The resultant subaqueous pyroclastic flow generated the Motoyama pyroclastic deposit. Then, the eruption center shifted to the Suribachiyama area, which is just outside the southwest caldera rim. Deposits from three different eruption periods have been identified-lower, middle, and upper pyroclastic deposits-and a lava flow that erupted during the middle pyroclastic period. The lower unit was formed by a subaqueous eruption at a deeper level; the middle deposit was formed by a phreatomagmatic explosion at a shallow depth; and, the following lava emission generated a lava island. The upper pyroclastic deposit was generated by a combination of phreatomagmatic and Strombolian eruptions. Although the ages of these eruptions are not obvious, the first phase of the eruption occurred during the period between 2.7 kBP and 0.8-0.5 kBP, which is estimated from the age of the reworked deposit sandwiched between Motoyama pyroclastic deposit and the upper marine terrace X (Kaizuka *et al.*, 1983) deposit. The eruption of the upper deposit occurred before AD 1779 (ca. 0.2 kBP). The eruptive products described so far are covered with younger sediment from marine terraces and spits. Recently, small-scale deposits from phreatic explosions accompanied by geothermal and uplift activities have been found in various places on the island, but juvenile material has not been confirmed to exist in the products.

Keywords: caldera, subaqueous pyroclastic flow, subaqueous lava

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Investigation into transition magma after Caldera forming, Izu-Oshima Volcano, eastern Japan

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Izu-Oshima is a volcanic island located at the northernmost end of Izu-Ogasawara islands. The volcanic activity has been divided into "pre-caldera stage", "caldera forming stage", and "post-caldera stage" (Nakamura, 1964). Twelve significant eruptions occurred after the caldera formation (about 1500 years ago), and these ejecta are called "Younger Oshima Group" (referred to as YOG) (Nakamura, 1964).There have been several petrological studies that investigated temporal evolution of YOG magmas, showing that Mg# of the whole rocks tends to decrease monotonously with time after the caldera formation (e.g., Fujii et al., 1988). It has also been suggested that the magmas were essentially derived from a single evolving magma chamber without significant replenishment of a primitive magma (Kawanabe, 1991). In this study, to understand magmatic processes in more detail, we are performing a geochemical analysis on YOG products. As a preliminary report, here we present petrography and whole-rock compositions of eruptive products from YOG. We also evaluate the magmatic system with respect to alignment of craters from which YOG magmas were ejected.

In this study, 44 rocks were collected from YOG, as well as from products of the 1950 and 1986 eruptions, according to the geological map of the volcano (Kawanabe, 1998). The samples are lavas and scoria, and are basalt ~basaltic andesite un composition. The phenocryst content ranges 1.5~10 vol.%. The phenocryst assemblage consists of plagioclase, orthopyroxene, clinopyroxene, and magnetite. The samples can be petrographically divided into those including many magnetite microphenocrysts (Type1), those including plagioclase glomerocrysts (Type2), and those without magnetite microphenocrysts and plagioclase glomerocrysts (Type3). SiO_2 contents range from 52 to 58 wt.%, but the contents of the samples other than those from the 1986 flank eruption are limited to 52~54 wt.%. In some Type2 samples, Al_2O_3 contents correlate positively with the modal abundance of the plagioclase phenocryst, but most samples have limited range in Al_2O_3 contents (14~15 wt.%) regardless of the abundance of the plagioclase phenocryst. The concentration ratios of incompatible trace elements (e.g., Ba/Zr) are essentially constant. In a histogram of the An content of the cores of the plagioclase phenocryst, a remarkable peak is observed at An=90 throughout the eruption stages in YOG. On the other hand, the An content of the rims of the plagioclase phenocrysts tends to decrease from older to younger samples. The plagioclase phenocrysts with reverse zoning are commonly observed in samples from the caldera forming stage, while they are scarce in samples from the following stages.

The ratios such as Ba/Zr are constant in the YOG samples, which suggests that the magmas were derived principally from a single primary magma. The observation that reversely-zoned plagioclase phenocrysts occur especially in samples from the caldera forming stage may suggest that magma mixing was dominated in the early stage of YOG, but it did not play an important role in most of the evolution after the caldera formation. On the flank of the main edifice, craters are aligned on two different NW-SE lines, and the flank craters of the 1986 eruption seem to be aligned on a line between them. We found that whole-rock compositions of the ejecta differ with respect to craters from the three lines. This observation may suggest that three discrete magma chambers with variable degrees of differentiation have been present beneath each line, while they were derived from a single primary magma.

Keywords: Izu-Oshima, petrology, volcanology, magma-plumbing system

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Magma mingling of the Kagusa lava in the Kusatsu-Shirane volcano: preliminary results from analyses of a boring core

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Three borehole-type seismometer and tiltmeter were installed around the Yugama crater in the Kusatsu-Shirane volcano by the Kusatsu-Shirane volcano observatory, Tokyo Tech. NE observation well was penetrated into the Kagusa lava which thickness was about 50 m (Uto et al., 2004). Hayakawa (1983) reported that Kagusa lava flowed from neighborhood of the Mizugama crater to east valley along the Oosawa river about 7,000 years ago. Whole-rock chemical compositions of Kagusa lava which samples were collected subaerially were analyzed by many studies (e.g. Hayakawa 1983, Uto et al. 1983, and Takahashi et al. 2010) and range from andesite to dacite (from 58 to 65 wt.% SiO_2). Kagusa lava often displays banded texture of andesite (gray color) and dacite (white color) in a flow unit at intervals of dozens of centimeter and flowed with mingling andesite and dacite together (Uto et al., 1983). In order to understand the time and space scale of magma mingling of eruption of Kagusa lava, in this study, depth profile of whole-rock compositions for this boring core was researched for every several meters based on description of this core (Uto et al., 2004).

Core samples were cut into homogeneous fractions which had no banded texture and each fractions were powdered. Some core samples which had complex mingling texture were powdered as a whole. Eleven times diluted glass beads were prepared for each sample using $Li_2B_4O_7$. Major elements of whole-rock compositions were analyzed using XRF (RIGAKU RIX2100) which was installed at Tokyo Tech. In the results, two groups were recognized in the compositions of most samples; group (1) corresponded to ~60 wt.% SiO_2 (andesite) and group (2) corresponded to ~65 wt.% SiO_2 (dacite). In view of the whole trend, intermediate samples which compositions corresponded to 62-63 wt.% SiO_2 lay along mixing trend between group (1) and (2). Core samples above ~35 m in depth were dominated by dacite and those below ~35 m in depth were dominated by andesite. This profile was consistent with core description of NE observation well (Uto et al. 2004). Some lower core samples which was collected below ~50 m in depth sometimes displayed banded texture of andesite and dacite. Judging from this results, regarding compositions, magmas of group (1) and (2) were mingled together immediately before eruption and mingled magma had no time to homogenize. In order to discuss mingling time scale in detail, I will carried out petrological study; phenocryst assemblage, composition, and zoning profile of phenocryst in the regions of contact will be researched.

Keywords: magma mingling, magma mixing, Kusatsu-Shirane volcano

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Geological map of Zao volcano

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We present new geological map of Zao volcano, as Geological Map of Volcanoes 18 by GSJ.

Zao volcano is a Quaternary stratovolcano located in the middle part of the volcanic front of northeast Japan arc. The volcanic activity started at ca. 1 Ma, and has continued to the present. The activity can be divided into six stages.

Stage I: The eruption products of ca. 1 Ma are hyaloclastites and dikes. These eruptions would have taken place under lake water. Rocks are tholeiitic basalt to andesite. Stage II: Around 0.5 Ma, activities of mainly lava effusion were taken place in the northern part. Stage III: During ca. 0.35 to 0.25 Ma, several small to middle sized andesitic to dacitic edifices were formed at the central part. At the end of this stage, small sized ediffice of basaltic andesite lavas was formed. Stage IV: During ca. 0.25 to 0.20 Ma, andesitic to dacitic lavas were swelled out in the southern area, and formed middle sized volcanic ediffice. Stage V: From ca. 0.13 to 0.04 Ma, andesitic lava flows with pyroclastic materials erupted from several vents in the northern to central part, which constitute middle sized volcanic ediffice. Stage VI: The most recent stage of the Zao volcano began at ca. 35 ka, when the horseshoe-shaped erosion caldera (1.7 km in diameter) was formed in the central part. Numerous small- to medium-sized explosive eruptions of calc-alkaline basaltic andesite magmas have occurred since then. The youngest small ediffice Goshikidake building activity started at about 2ky. In this stage, small sized lava flows were rarely effused.

Systematic temporal change in petrologic characteristics can be observed. All eruption products of stage I belong to low-K tholeiitic series, while the others belong to medium-K calc-alkaline series. The potassium levels of stage II products are lower than those of stage IV and V products. Geologic units with both of those two potassium levels can be observed in stage III. The stage VI products show compositional trends crossing the boundary between low and medium-K series. More in detail, temporal and special variation in compositional trends within each stage can be observed. Especially, the variations are relatively intense in stage IV and V products.

From the record of AD 1230, many historic activities were recorded in written accounts. All were generated at the Okama crater lake. From 17th to 19th century, the eruptions continued for ca. 100 years with intermittent dormancies. In 17th, the eruptions have occurred in 1620-1625, 1641, 1668-70, 1694. From late 18th to 19th, the eruptions were taken place in 1794-96, 1809, 1831-33, 1894-1897. The activities are characterized by outbreak of lahar. Among the activities from AD 1894 to 1897, phreatic eruptions occurred. The latest volcanic activity in Okama occurred during 1939 to 1943.

Keywords: Zao, Volcano, Geological map

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Magma evolution and time scales of magma mixing of the Kumanodake agglutinate of Zao volcano, northeastern Japan

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To understand the evolution of magma system for the activity of newest stage (c. 33 ka to present) of Zao volcano in northeastern Japan, we have investigated the eruption products of the Komakusadaira activity (c. 33 ka to 12 ka). In this study, we will infer the evolution of magma system based on detailed petrological features of the Kumanodake agglutinate which was formed during initial period of the activity.

The Kumanodake agglutinate drapes the summit area of Mt. Kumanodake whose inner part is comprised by the older stage products. This unit piles up successively without any unconformity or secondary deposits. The succession is ca. 30 m thick, comprising stratified pyroclastic layers (agglutinate, agglomerate, tuff breccia, and lapilli tuff). The layers include various amount of black scoriae (~1m), gray andesitic bombs (~20cm), and subordinate amounts of gray andesitic lapillus to volcanic block in the matrix of reddish brown scoriaceous ash. The explosivity is inferred to have increased over time because the abundance of the scoriae increased. Futhermore, the large scoriae are usually found in the top part.

The rocks are mixed medium-K calc-alkaline olv-cpx-opx basaltic-andesite (55.2-56.2% SiO_2, 0.82-0.85% K_2O). From the base to the top, SiO_2 and Zr contents decreased gradually, whereas the CaO and MgO contents increased.

Based on petrologic features, we deduced the products were formed by magma mixing of felsic magma and mafic magma. The estimated felsic magma (59-62% SiO_2, 956$\pm$17 degrees Celsius in the lower part and 967$\pm$22 degrees Celsius in the upper part) with orthopyroxene (Mg# = 60-69), clinopyroxene (Mg# = 65-71), and An-poor plagioclase ($An_{ca.60-70}$) was stored in a shallower region. The mafic magmas are further divisible into two types: less and more differentiated, designated respectively as mafic magma-1 and mafic magma-2. The less differentiated mafic magma-1 was olivine (Fo_{84}) basalts (ca. 49-51% SiO_2, 1110-1140 degrees Celsius). The differentiated mafic magma-2 was basalt (1070-1110 degrees Celsius) having olivine ($Fo_{ca.80}$ with reverse zoned part of Fo_{84}) and An-rich plagioclase ($An_{ca.90}$) phenocrysts was the basalt formed occasionally at 3-6 km depth. The mafic magma-1 was the dominant mafic magma because of Fo_{81-84} olivine phenocrysts are more common than Fo_{76-80} ones.

We estimated the time scales from magma mixing to the eruption on the basis of zoning analysis of olivine (Fo_{84}) phenocrysts rim (~50 μm from phenocrystic optical edge) and diffusion calculations. The zoning analysis revealed that a significant mixing process occurred 250 days to 3.5 years before the eruption in the lower part, while 15 to 130 days in the upper part. In the lower part, up to 40% An-poor plagioclase and orthopyroxene phenocrysts in the same thin section have multiple dusty zones or oscillatory zoning part inside the phenocrystic rim. The abundance of those phenocrysts decreases 15% up-section. These phenocrysts are antecrysts formed by injection of mafic magma prior to the eruption. Thus, the duration of the time scale correlates to the amount of antecrysts. Consequently, in the early part of the activity, the erupted magmas had more antecrysts.

The erupted magma composition became more mafic, which reflects increased percentage of mafic magma involved in mixing. At the beginning of the activity, the mafic magma also acted as a heat source for activation of the cold felsic magma chamber, thereby suppressing the volume percentage of mafic magma in the mixing, and also resulted in longer residence time before the eruption. As the activity proceeded thereafter, the shallow felsic chamber would become more mobile, consequently the mafic would be able to mix with felsic magmas more easily, resulted in higher percentage of the mafic magma in the mixing, and prompt eruption.

Keywords: Magma evolution, Magma mixing, Time scale, Kumanodake agglutinate, Zao volcano, NE Japan

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Petrologic characteristics of early part of the Okama-Goshikidake activity of the Zaovolcano.

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Introduction: Zao volcano is representative active stratovolcano in NE Japan. The volcanic activity commenced at about 1Ma and has continued to present. The Goshikidake, the youngest cone in the central part, started its activity from ca. 2ka. The present crater lake Okama is in the western part of the Goshikidake. We examined the geologic and petrologic features of the eruption products in the initial period of the Okama-Goshikidake activity.

Stratigraphy: The eruption products can be subdivided into Furikodaki lava, Goshikidake-nanpo lava and pyroclastics, Goshikidake-nanbu pyroclastics, Goshikidake-toubu pyroclastics. The Furikodaki lava flowed down from the northeastern base of the Goshikidake cone along a stream. The length and width of lava are ca. 750m and 20-30m, respectively. The Goshikidake-nanpo lava and pyroclastics cropped out in a narrow area of ca. 650m south from the summit of Goshikidake. This unit is composed of upper brecciated lava with coarser lateral and finer vertical joints, and lower hyaloclastite-like tuff breccia. Goshikidake-nanbu pyroclastics distributes ca. 500m southward from the summit, consisted of pyroclastic surge deposit and vent breccia. The former consists of lapilli tuff to volcanic breccia with ca. 10m in thickness. The latter consists of three veins elongated from northeast to southwest with 2-8m width and 5-8m length. These intrude nearly vertically into surge deposits. They are poorly sorted tuff breccia with minor amount of ˜20cm rounded bombs. The Goshikidake-toubu pyroclastics distribute in ca. 300m eastward from the summit. The thickness is ca. 6-35m. They are fairly stratified tuff - lapilli tuff - tuff breccia including various amounts of volcanic bombs.

Petrography: All rocks are cpx-opx andesites. Most of plagioclase phenocrycrysts has dissolution textures such as dusty zone and/or patchy zoning. Plagioclase of the Furikodaki lava, the Goshikidake-nanpo lava and pyroclasts lack dusty zones. Opx and cpx phenocrysts show usually euhedral to subhedral texture except for some rounded cpx phenocrysts. About half of the pyroxene phenocrysts include sparsely glass inclusions. Cpx content in the bombs of the vent breccia of the Goshikidake-nanbu pyroclastics is higher than other products.

Whole rock chemistry: All products belong to medium-K, calc-alkaline series, with 56 to 58% SiO_2. Looking at in detail, the range of SiO_2 contents of Furikodaki lava, Goshikidake-nanpo lava and pyroclasts is 57.5-58wt%, while that of the other products is 56-57.7wt%. Most of the products are plotted in same variation trends in silica variation diagrams, but the bombs of the vent breccia have higher FeO, TiO_2 contents and lower MgO contents than the other products.

Mineral chemistry: In Furikodaki lava, Goshikidake-nanpo lava and pyrocrastics, the core composition of opx phenocrycrysts is 64-65 Mg#. In the pyroclastic surge deposits, that is around 65 Mg#. In the bombs, that has a range of Mg#62-69. The cpx core composition shows a range of ca. 64 to 70 Mg# in all products. The core compositions of plagioclase phenocrycryst show wide range of An62-92. In Furikodaki lava, Goshikidake-nanpo lava and pyrocrastics, the main peak compositions are in An68-70 and around An78, and subordinate peak is in An90. The pyroclastic surge deposits have main peak compositions of An64-66 and An76-78, subordinate peak composition of An90. The bombs have main peak compositions of An62-66 and An74-76.

Keywords: zao volcano, andestic lava, pyroclastic surge, agglutinate, calc-alkaline

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Petrological characteristics of rocks from Chokai A.D.1800-1804 activities, NE Japan

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Chokai volcano is a Quaternary stratovolcano located at rear arc of the Northeast Japan. The activity is divided into three stages (ca. 0.6 Ma ; Stage Ⅰ, ca. 0.16Ma to 20ka; Stage Ⅱ, 20ka to present; Stage Ⅲ). In historical age, magmatic and phreatic eruptions occurred at least three and four times, respectively. One of the historical magmatic eruption occurred two years after the big earthquake of AD 869. Thus, this volcano has a potential to erupt after the 2011 off the Pacific coast of Tohoku Earthquake, but no precursory phenomena have been detected yet. To reveal the magma feeding system, we examined geologic and petrologic features of youngest (AD1800-1804) magmatic eruption products.

The AD1800-1804 eruption products are composed of Shinzan lava (SL), Shinzan pyroclastic fall deposits (SPFD) and Shinzan dome lava (SLD) in ascending order. SL is consisted of mainly two lava flows, one flowed to the southward and the other to northward from SLD. Maximum thicknesses of southern and northern lobe are 50m and 25m, respectively. Total volume is ca. 7.3×10^{-3}km^3. These are massive lavas and the surfaces are composed of the blocky lava. Mafic inclusions can be observed in these lavas. SPFD drapes the SL within ca. 50m from SLD. The thickness varies and reaches ca. 30cm near the base of SLD. The estimated volume is 9.0×10^{-7}km^3. The deposit is lapilli tuff to volcanic breccia, composed of mainly angular lithic fragments in coarse ash matrix. Most of the fragments have shiny surfaces. Subangular to subrounded pumice is rarely observed, whose diameter reaches ca. 5cm. Volcanic bombs are observed in the area of ca. 500 m radius from SLD. These usually cover the SPFD, thus we include them into the SPFD. These are mainly breadcrust bomb and subsequently breccia bomb, which looks like a fragment of the explosion breccia. Mafic inclusions are generally seen in breadcrust bombs, but rarely breadcrust bombs are made of only mafic inclusion. Breccia bombs are consisted of angular rubbles of several centimeters to one meter in weak welded matrix. SLD forms a peak dome of Chokai volcano. Relative elevation of SLD is 50m, volume is 9.0×10^{-4}km^3. Columnar and platy joints can be observed inner of dome. Mafic inclusions are seen.

AD1800-1804 eruption products belong to medium-K to high-K, calk-alkaline series. Phenocryst assemblage is plagioclase, orthopyroxene, clinopyroxene, opaque $\pm$ olivine and hornblende. Plagioclases with resolved texture such as dusty zone and honey comb texture dominate than the clear type. Orthopyroxene and olivine sometimes have a reaction rim, but hornblende doesn't have it. Volumes of total phenocrysts in the hosts are high in SL (48-50vol.%) than the others (26-36vol.%). Those of mafic inclusions are 20-30 vol.%. Groundmass texture of host lava is hyaloophitic, while that of inclusion is dikty-taxitic. Size of microlites in the inclusions varies by samples. SiO_2 contents of host lavas are ca. 60-62wt.% (SL, 60.7-60.8 wt.%; SPFD pumice 60.7-61.2 wt.%; SPFD lithic fragments, 60.8-61.1 wt.%; SPFD volcanic bomb, 60.5-61.5 wt.%; SPFD breccia bomb, 60.7-61.0 wt.%; SLD, 61.2-62.2 wt.%) and those of mafic inclusions are ca. 52-57wt.% (SL 53.3 wt.%; SPFD lithic fragments, 54.2 wt.%; SPFD volcanic bomb, 56.5 wt.%; SPFD breccia bomb, 52.6-54.8 wt.%; SLD 54.0-55.8wt.%). All eruption products are depicted on the same linear trends in silica variation diagrams.

Keywords: Chokai volcano, eruption history

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Eruptive sequence and magma system of the latest large silicic eruption of Kuttara volcano (Kt-1), southwestern Hokkaido

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Kuttara volcanic group, located in southwestern Hokkaido, started its eruptive activity ca. 80 ka. The volcano has repeated the large silicic eruptions several times. The youngest large silicic eruption (Kt-1) occurred ca. 42 ka, forming the present Kuttara caldera (Yamagata, 1994; Moriizumi, 1998). Total volume of Kuttara volcanic group is more than 100 km^3, being comparable to those of Shikotsu and Toya caldera volcanoes that locate near Kuttara volcanic group. However, it has not been still understood the reason for the multiple eruptions of voluminous silicic magma. In order to resolve this problem, it is important to reveal the eruptive sequence and the evolution of magma system. Therefore, we has carried out the geological and petrological studies about Kuttara volcanic groups. In this presentation, we reexamine the eruptive sequence of Kt-1 eruption and discuss the relationship between eruptive sequence and magma system.

Moriizumi (1998) recognized that Kt-1 pyroclasts are composed of pyroclastic falls (Kt-1pfa), pyroclastic flow (Kt-1pfl), and pyroclastic surge (Kt-1ps). Kt-1pfa is divided into lower and upper units (Kt-1 pfa1 and Kt-1 pfa2, respectively) on the basis of scoria fall deposits (Kt-1sfa). Kt-1 pfa1 includes hornblende-bearing pumices, whereas Kt-1 pfa2 is absent from such pumices. Kt-1 pfl has also no hornblende in pumices, and therefore, it is interpreted that Kt-1 pfa2 and -pfl occurred simultaneously.

In this study, we can divide pyroclastic falls into five units according to the time gaps on the basis of weathered layers of the top of each unit: from Kt-1A to Kt-1E in ascending order. In Kt-1A, -1B and -1C, there are some pumices including hornblende, whereas pumices in Kt-1D to Kt-1E have no hornblende. This suggests that units from Kt-1A to Kt-1C and from Kt-1D to Kt-1E respectively correspond to Kt-1 pfa1 and Kt-1 pfa2 defined by Moriizumi (1998). In addition, we recognize the pyroclastic flow and surge deposits, agreeing with Kt-1pfl and Kt-1ps, respectively. The pyroclastic falls comprise of white and banded pumices, and pyroclastic flow includes white pumice, scoria, and banded pumice˜scoria. Phenocrystic minerals of all the juveniles are quartz, plagioclase, orthopyroxene, clinopyroxene, and opaque minerals. On whole-rock chemistry, the juvenile materials of Kt-1 eruption show 59.2-74.1 wt.% in SiO_2. We identify four compositional trends, being clearly different in many Harker diagrams. On the basis of the compositional trends as well as mineral assemblage, we classified Kt-1 juveniles into four types as follows. Type1 is the most silicic rhyolite including hornblende. Type2 is a hornblende-free rhyolite and rhyodacite rock. Type3 is dacite having a small amount of hornblende. Type4 is characterized by wide compositional variation from rhyolite to andesite without hornblende. The compositional trends of Type1, -2, and -3 are clearly distinct at both silicic and mafic sides. In contrast, Type4 shows the compositional trend converging to Type2 at silicic side.

Considering the temporal change of juvenile types, components change with the progress of eruption. Type1 and -3 are present in Kt-1A. In Kt-1B and -1C, however, Type1 disappears and Type2 and -3 are found. In Kt-1D and -1E, only Type2 occurs. On the other hand, in Kt-1pfl, there is only Type4 juveniles. The difference in types of juveniles between pyroclastic falls and flow suggests that pyroclastic flow did not occur simultaneously with Kt-1D and -1E (Kt-1pfa2). The compositional trends for whole-rock chemistry of Type2 and -4 converge at silicic side. This indicates that pyroclastic flow generated after pyroclastic fall eruptions.

We recognize four types of juvenile materials in Kt-1 eruption. That is, four types of magma erupted in Kt-1 eruption. These magmas had been active in turn as the eruption progressed, suggesting the relationship between eruptive sequence and magma system.

Keywords: Kuttara volcano, caldera volcano, caldera-forming eruption, silicic magma, Petrological features, magma chemistry

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Petrology of pre-caldera eruption of Shikotsu volcano (Shadai pyroclastic flow), Southwestern Hokkaido

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Shikotsu volcano started large-scale eruption at 60ka, and erupted scoria fall and scoria flow (Shadai pyroclastic flow=Shadai pfl) deposits. The volcano repeated explosive eruptions every several thousands years, and after 10ky dormancy, caldera-forming eruption took place at 40ka. Eruptive volume of pre-caldera eruption is less than 50km^3 and that of caldera-forming eruption is ca. 400km^3 (Yamagata, 1994). We collect samples of Shadai pfl from continuous boring core, 5km-south of lake Shikotsu (JMA-V05), and clarify petrological characters to compare with those of caldera-forming eruption.

The boring core consists of soil (0-1.8m), reworked deposits (1.80-2.60m depth), Shadai pfl (2.60m-3.40m), reworked deposits (3.40m-4.25m), Shadai pfl (4.25m-18.15m), reworked deposits (18.15m-19.90m) and Shadai pfl (19.90m-101.00m), and the lowest part of pfl cannot be seen (Takarada and Furukawa, 2010). Shallow part of Shadai pfl ($<$18.15m) is non-welded. Juvenile materials consist mainly of banded pumice and small amount of white pumice. Weakly to strongly welded parts exist in the deeper part (53.40m-72.00m and $>$80.90m are strongly welded). Most of the juveniles of these parts are scoria and banded pumice.

Juvenile materials of Shadai pfl are SiO_2=53-62wt% andesite and dacite. They contain 20-40vol% phenocrysts of plagioclase, orthopyroxene, clinopyroxene and oxides (sometimes accompanying olivine). Banded pumice is heterogeneous in microscopic order. They usually make linear trends on Harker diagrams. SiO_2 contents of white pumice are $SiO_2>$60wt%, and most of scoria are $SiO_2<$56wt%. Furthermore, SiO_2 contents changes with depth. Rocks of $<$18.15m consist only of SiO_2=60-62wt% dacites, but SiO_2-poor materials appear from 19.90m. Andesites of $SiO_2<$53wt% are often found in 53.40m-72.00m and compositional range becomes the maximum. Then, SiO_2 contents concentrate to 55-62wt% in $>$72.00m. REE contents increase with SiO_2, however chondrite-normalized REE patterns are scattered in LREE. Ratios of MREE/LREE and HREE/LREE, together with Y/Rb, Zr/Rb and Ba/Rb, decrease as increasing SiO_2. Isotopic ratios of Sr and Nd are nearly constant for wide SiO_2 range.

Existence of banded pumice, heterogeneous texture under microscope and linear compositional trends suggest that Shadai pfl is produced mainly by magma mixing of mafic and felsic magmas. Difference of compositional range of each depth reflects that mixing ratios has changed with time. According to the constant isotopic ratios and decreasing of MREE-HREE/LREE, Y/Rb, Zr/Rb, Ba/Rb with increasing SiO_2, end-member magmas cannot be produced by simple crystal differentiation but by different degree of partial melting from the same crustal material.

Caldera-forming eruption of 40ka started with phreato-magmatic eruption and then occurred plinian eruption to flowed down the pyroclastic flow. The juveniles are classified into 2 types; dacitic to rhyolitic A-type ($<$5vol% phenocrysts, SiO_2=74-78wt%) and andesitic to dacitic P-type (7-45wt% phenocrysts, SiO_2=57-72wt%). A-type rocks can be seen throughout the caldera-forming eruption, but P-type exists only in the upper unit of pyroclastic flow (Nakagawa et al., 2013). Phenocryst assemblage is plagioclase, orthopyroxene, clinopyroxene, hornblende and oxides. There are evidences of magma mixing for both A and P types, however end-member magmas are different from each other. Nakagawa et al. (2010) shows that felsic magma of Shadai pfl is similar to P-type dacite of caldera-forming eruption, and suggests that the felsic magma mixes with mafic magma of low Sr isotope. As we reanalyze REE compositions and isotopic ratios of caldera-forming eruption, Sr isotopic ratio of Shadai pfl is slightly lower and Nd ratio is higher than caldera-forming eruption and Nd isotope of these eruptions make parallel trends. These suggest that origin of these eruptions is different and new magma should be produced after pre-caldera eruption.

Keywords: Shadai pyroclastic flow, pre-caldera eruption, caldera-forming eruption, magma mixing, origin of magmas

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The sequence of caldera-forming eruption of Shikotsu caldera inferred from component analysis

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Shikotsu caldera, located at southeastern Hokkaido, was formed ca. 42ka. The caldera forming eruption has been studied in detail. The eruption started with phreatomagmatic eruption, followed by plinian eruption to deposit. In final, pyroclastic flows (Spfl) were produced to form the Shikotsu caldera (Katsui, 1959). Yamagata (1992) revealed the detail sequence of the caldera-forming eruption and emphasized the presence of lag-breccia in the upper part of Spfl to discuss the formation of the caldera. In addition, Nakagawa et al. (2006) revealed temporal variation of magma type during the caldera-forming eruption to discuss the relationship between caldera formation and magmatic processes. However, the relationship between eruption sequence and temporal variations of eruptive materials has not been well revealed. Recently, good outcrops have occurred at the southern area of Shikotsu caldera, where the whole sequence of the caldera-forming eruption can be observed. We describe these deposits and carry out component analysis of representative samples. Based on these data, we discuss the eruptionsequence and caldera formation processes. In newly formed outcrops, we can observe tephra layers for 60 ky. The tephra of the caldera- forming eruption of Shikotsu caldera can be divided into 5 eruptive phases, based on the mode of eruption and emplacement. Phase1 is defined as phreatomagmatic deposits. After that, a seriesof plinian eruptions occurred(Phase 2). After possible erosional gap, large scale and high energy pyroclastic flow erupted (Phase3). The lowermost flow sometimes include the block of deposits of the Phase 2, suggesting that the flow was energetic to erode the surface. Following pyroclastic flows of Phase 4 are characterized by the presence of thick lithic concentration layer. After that, the scale of eruption had decresed to depost thin surge deposits and pumice fall deposits (Phase5).

We collected sampls for the component analysis from 40 horizons. Lithic fragments of each unit composed of sedimentary rocks (shale and sandstone), volcanic rocks (two pyroxene andesite), and altered rocks. And rarely contain fragments of plutonic rocks and minerals. The weight ratio of lithic in these layers is usually less than 30%. Not only the weight ratio of lithic breccia but also the ratio of lithic types temporally change. The weight ratio of lithic breccia becomes quite high in the upper layer of Phase 2. These suggest the vent widening and/or migration during early stage of the caldera-forming eruption. In Phase 3, the types of lithic breccia had not changed. The lithic concentration layer in the deposts of Phase 4 is most voluminous among all deposits. We will investigate the temporal variation of juvenile materials based on our newly revealed stratigraphy.

Phase1 is characterized by high content of volcanic rocks but, in early plinian eruption, that generally as high as 50 wt.%. And, in the plinian eruption medium phase, volcanic rock on behalf of the sedimentary rocks content increases. This suggest vent is moved from phase1 through phase2, after that column became unstable by vent expansion. And when phase2 late dropped to about 20 wt.%, became higher of content of volcanic rocks and altered rocks , and there is also unit reaches 70%. Therefore, in phase2 later, expansion and movement of the vent is suggested on a large scale. Lithic fragments type in phase2 later feature is followed by phase 3. That suggests a large scale vent movement and expansion was not over the pyroclastic flow eruption in Phase 3. Lithic breccia layer containing more than 70% of the lithic fragments in phase 5 is the most large scale in this outcrop, also is observed new volcanic rock type. This shows activities from a new vent and the vent expansion on a large scale. Thus, this phase was a mature stage of caldera-forming. In the future, in addition to the process of caldera-forming eruption to attempt to elucidate the detailed magma transition.

Keywords: caldera-forming eruption, tephrastratigraphy, component analysis, eruption sequence

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Magma mixing processes and origin of mafic inclusions for the Mikurasawa lava in the Taisetsu volcano, Hokkaido, Japan

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The Mikurasawa lava, in the Taisetsu volcano is a lava flow erupted from the outside in southeastern the Ohachidaira caldera. Most of the lava consist of andesite (SiO_2=60.6-57.3 wt. %). Some parts of the lava consist of dacite (SiO_2=63.6-62.4 wt. %) and banded lava constructed with andesite and dacite. In addition, the andesite has some mafic inclusions (SiO_2=58.0-51.3 wt. %). The Mikurasawa lava is a rare because of coexisting banded lava and mafic inclusion. This study elucidates magma mixing processes and origin of mafic inclusions of the Mikurasawa lava by petrological method.

I considered that the andesite of the Mikurasawa lava formed by magma mixing on account of existing of banded lava and mafic inclusions, coexisting of plagioclase which have different composition and showing reverse zoning in plagioclase phenocryst. Many plagioclase in the andesite show resorbed texture in core and reverse zoning in rim. It indicates that the andesite experience several times of injection of mafic magma. I estimate that a period from initial inject to eruption was about 60-600 years by element diffusion rate. The phenocrysts in the andesite are classified into two crystal groups (type-A and -B) by the core composition. The phenocrysts of each crystal groups derived from same magmas because they form crystal clots each other. Type-A crystal group consists of high-An plagioclase, high-Mg♯ orthopyroxene, high-Al_2O_3 clinopyroxene and olivine. These crystals were derived from mafic magma. Type-B crystal group consists of low-An and low-MgO plagioclase, low-Mg♯ orthopyroxene and low-Al_2O_3 clinopyroxene. These crystals were derived from felsic magma. I estimated the temperature of the mafic and felsic magmas by two-pyroxene thermometer. The results are about 1000 ℃ and 900 ℃.

The mafic inclusions in the Mikurasawa lava show various texture and composition. I classified them into three types (Type-1, -2 and -3) by size of plagioclase. Type-1 mafic inclusion has fine-grained acicular plagioclase in groundmass. Type-2 mafic inclusion has coarse-grained tabular plagioclase in groundmass. Type-3 mafic inclusion consists of bigger plagioclase than the other mafic inclusions most of which are phenocrysts.

I considered the origin of each types of mafic inclusions from texture and composition. The type-1 mafic inclusion is characterized by fine-grained crystals and these compositions which are similar to those of microphenocrysts of the andesite. Therefore, it seems that this mafic inclusion formed by quenching of hybrid layer magma between mafic and felsic magma in the reservoir. The type-2 mafic inclusion is characterized by coarse-grained groundmass crystals and these compositions which are similar to those of crystals of dacite. Therefore, it seems that this mafic inclusion formed by disruption and inclusion of crystal mush layer of felsic magma during eruption. The type-3 mafic inclusion is formed by inclusion of mafic magma because of being composed of type-1 crystal group.

I considered magma mixing processes in magma reservoir of the Mikurasawa lava based on above date. First, felsic magma reservoir having crystal mush layer was injected by mafic magma. This injection occurred partial melt of plagioclase in felsic magma, forming resorbed texture. Furthermore, at a boundary between felsic and mafic magma, hybrid layer was formed by magma mixing. After 60-600 years, reinjection of mafic magma occurred eruption. During eruption, andesitic magma formed by mixing of mafic and felsic magmas. Felsic magma which was not affected by mafic magma formed dacite and banded lava. Hybrid layer and mafic magma included in andesitic magma, forming Type-1 and Type-3 mafic inclusions respectively. Crystal mush layer was disrupted during magma ascent. The fragment was included in andesitic magma, forming Type-2 mafic inclusion.

Keywords: magma mixing, mafic inclusion, Taisetsu volcano, Mikurasawa lava, plagioclase phenocrysts

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The formation process of obsidian; Insights from the application of TTT diagrams to Tokachi-Ishizawa obsidian

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Why obsidian contains low crystal amount, namely mostly glass, though it experiences the effective undercooling and long crystallization time during magma ascending and cooling, has been a big problem in volcanology. In generally speaking, glass can be formed because of a high effective undercooling and a short cooling time. However, ascent rates of obsidian lava eruption are expected to be relatively small.

In order to evaluate the development of glass formation in obsidian lava eruption, we applied Time- Temperature- Transformation (TTT) diagram for natural obsidian lava, and estimated critical cooling rate to form the obsidian. The TTT diagram has been used to predict the cooling rate to form the glass (Uhlmann, 1982; Weinberg and Uhlmann, 1989; Rao 2002). The TTT diagram is a contour map of crystallized volume fraction as function of crystallization temperature and time. A contour line for a given crystallization fraction has the cone shape with its “nose” which corresponds to a minimum time and a temperature required for the time. We simulated the 2 types of situations; decompression-induced crystallization and cooling-induced crystallization after decompression. The nucleation and growth rate were calculated based on the classical theory (James, 1985; Hammer, 2004; Rao, 2002). The crystallized fraction, under the assumption that nucleation and growth rate are constant for time, is given by the Avrami-Johnson-Mehl equation. We applied TTT diagram for Tokachi-Ishizawa obsidian lava, and estimated the critical cooling rate. Based on the calculation results, critical cooling rates are highly dependent on interfacial energy and the pre-exponential factor of nucleation rate.

We compared estimated critical cooling rates with cooling rates estimated from the microlites number density (Sano et al., 2015). Our calculation results show that obsidian glass can be formed during decompression and cooling, especially under the high interfacial energy. We investigated the glass forming conditions based on parameters such as interfacial energy and pre-exponential factor, and suggest that obsidian can be formed although it experienced the low effective undercooling and long crystallization time during eruption.

Keywords: obsidian lava, glass, rock texture, Hokkaido, Shirataki

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Factors governing fragmentation of submarine lava - mechanism of hyaloclastite formation

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Hyaoclastite is produced by fragmentation of lava when stress accumulates on solid lava faster than it relaxes and ultimately reaches the mechanical strength of the lava. Thermal stress, shear stress and tensile stress acculumating on the lava crust are relaxed by viscous flow of lava, which is governed by viscosity. Therefore, fuidal basalt lava tends to form coherent flows without fragmentation, whereas viscous lava such as andesite and dacite tends to form hyaloclastite. Hyaloclastite with a wide compositional range spanning from andesite to rhyolite is associated with pillow flows and dikes in the Eocene submarine volcanic strata on Chichijima, Ogasawara Archipelago (Umino and Nakano, 2007). These volcanic ejecta are ideal to assess the effect of varying lava composition on the factors that govern the fragmentation of lava.

Quenched glass from chilled margins of pillow and hyaloclastite were collected and analyzed by EPMA for major elements and by SIMS and FTIR for water contents. The amount of primary, magmatic water was discerned from secondary hydration by differential thermal analysis. Eruption temperatures were estimated by the clinopyroxene-liquid geothermometer of Putirka (1999). Crystal number densities of groundmass plagioclase and clinopyroxene were determined on COMPO images and modal abundance of constituent minerals was determined on elemental distribution maps of EPMA. Bulk viscosity of lava was estimated by the methods of Giordano et al. (2008) and Pinkerton and Stevenson (1992).

Andesite consists of clinopyroxene, orthopyroxene, plagioclase and magnetite as phenocrysts set in a groundmass of clinopyroxene and plagioclase microlites, magnetite and glass. In Nagasaki, pillow lava coexists with hyalcoastite. In transition zones from pillow lava to hyaloclastite, pillow lobes are scattered in hyaloclastite. Hyaloclastite is higher in crystal number density, mode of groundmass plagioclase and vesicle number density than the associated pillow lava. Hyaloclastite glass is lower in Al_2O_3 than associated pillow glass, indicating plagioclase fractionation. However, the cpx-saturated melt temperatures show little difference between pillow lava and hyaloclastite. Water contents in glass were determined by using FTIR, which are almost identical in pillow and hyaloclastite. However, primary water contents estimated by differential thermal analysis are lower in pillow lava than in hyaloclastite. Therefore, degassing either within the conduit or during flowage through lava tubes induced plagioclase crystallization that raised the bulk viscosity of lava and stress relaxation time, resulted in the formation of hyaloclastite. However, higher water contents in hyaloclastite suggest that the hyaloclastite was formed by spalling off of chilled margin glass from pillows.

Dacite has phenocrysts of clinopyroxene, orthopyroxene, plagioclase and magnetite in the groundmass of clinopyroxene and plagioclase microlites, magnetite and elongate or spherical vesicles. The dacite shows little difference in melt composition, eruption temperature, crystal number density between pillow lava and hyaloclastite. In Ogamiyama and north of Manjumisaki, lower water contents in hyaloclastite indicate fragmentation occurred due to degassing and increase in bulk viscosity. On the other hand, in Zonahanasaki and Sakaiura, dacite pillow lava has lower water contents than the associated hyaloclastite, which may have formed by spalling off of chilled margins or by fragmentation of pillow lava crust due to higher shear stress.

Keywords: hyaloclastite, viscosity, submarine lava, the Bonin Islands Chichijima

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Emplacement and solidification process of off-axis large submarine lava field from the Oman Ophiolite

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Large submarine lava flows more than 100 m in thickness and a volume exceeding a few cubic kilometers are not uncommon volcanic constructs of mid-ocean ridges and Hawaiian volcanoes, yet details of the physical processes of emplacement of such large flows are poorly constrained because of their inaccesibilty under deep water and lack of direct observations. The V3 Volcanics of the Oman Ophiolite extruded at 90 Ma far off the paleospreading axis as thick lava flows with a minimum areal extent of >11 km by 1.5 km and the maximum thickness >270 m, yielding a minimum estimated volume of several cubic kilometers. The V3 flow was fed through a thick feeder dike in the SW of the flow field and buried off-axial fault-bounded basins with a thick sedimentary cover in ca. 40 days. The basic structure of the V3 flows consists of massive lava sandwiched between columnar jointed lava crusts, similar to that of subaerial flood basalt. The upper crust comprises piled up flow lobes forming dome-like structures with occasional inflation cracks, which are interpreted as welded aggregates of coalesced and inflated flow lobes. V3 flow is roughly divided into the Upper and the Lower flow by the presence of pillow lava with interstitial mudstone. Thickness of individual lobes varies from 2 to 20 m. The uppermost 35 m comprises at least eight welded flow lobes, averaging 3.4 m in thickness.

Low-T hydrothermal alteration and weathering slightly modified the bulk compositions as indicated by moderately albitized plagioclase, completely replaced olivine by clay minerals and partially replaced titanomagnetite and augite by titanite and actinolite, respectively. However, HFSEs and REEs show mutual positive correlations and relatively good correlations with some major elements besides LILEs and Pb, indicating that these elements were less mobile and preserve primary characteristics. V3 flow is hawaiitic-mugearitic dolerite and has intermediate characteristics between OIB and E-type MORB. TiO_2 shows a moderate increase with decreasing MgO from 8 to 5 wt%, and then decreases with the decrease in MgO down to 4 wt%, whereas Yb ranges from 2.12 to 4.56 ppm.

Whole-rock major and trace element variations through a stratigraphical transect at a distance of 8.7 km from the feeder dike indicate fractionation of augite, plagioclase and magnetite. By contrast, other V3 samples show highly scattered whole-rock compositions, suggesting internal mixing of variably differentiated magmas. Yb concentrations of the basal crust increase downflow to a distance of 4.5 km from the feeder dike, and then decrease further downflow with a spike at 7 km. Because the basal crust is the first lava that came to rest at that place, samples farther away from the feeder were extruded and emplaced later in the eruptive event. The downflow variations show extrusion of differentiated lava in the middle stage of the eruption and less differentiated lava in early and late stages.

Width/length ratio of groundmass plagioclase at 6 km from the feeder, where V3 flow is thickest, is higher in the Upper flow than in the Lower flow. Stratigraphic variations of Yb shows a decrease from the basal crust to a height of 26 m in the core, and then increase to a height of 83 m in the upper crust and decrease to the top of the Lower flow. The minimum Yb in the core is close to that of the latest lava shown by the basal crust. This can be reconciled with the model that the core is formed by the last intruded lava. On the contrary, the variation in Yb from the height of 83 m to the top of the Lower flow is correlatable to that of the basal crust at distances from 6 km to 8 km, suggesting that the upper crust consists of piled-up and welded lava lobes.

Keywords: Oman Ophiolite, V3, Large Lava Flow, emplacement process, chemical variation, geochemistry

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K-Ar ages of Samalas-Rinjani volcano cluster, Lombok: pre-caldera variation from migrating to stationary activity.

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K-Ar dating of Pliocene to Quaternary lavas consisting large volcanoes in Lombok are preformed to determine the active periods of Samalas-Rinjani volcano complex (VC) prior to the caldera eruption in 1257 CE. In order to accurately date the hand specimen of young lavas, non-spiked argon ratios are analysed to estimate the amount of mass fractionation of argon isotopes at the time of solidification of the lavas. Consistent ages were obtained for replicate analyses of the four young lavas from Samalas in the range of 0.08-0.04 Ma. Two samples are estimated to have initial argon ratios that are fractionated from atmospheric values. The ages form distinct groups that correspond to the active periods of volcano clusters: 2.7 Ma and 2.0-1.8 Ma for West Lombok VC, 0.5-0.4 Ma for East Lombok VC and 1.0 Ma to present for Samalas-Rinjani. Samalas-Rinjani system should be defined as single volcano complex based on the relative duration of each active period. Rinjani and the current activity of Segara Anak caldera are correlated to the younger stages of Samalas-Rinjani. The location of volcanism has been relatively stable for the past 0.4 million years in both Lombok and Sumbawa, which hosts Tambora volcano. Caldera-forming eruptions of the two regions (the 1257 eruption and the 1815 eruption at Tambora) occurred at the volcanoes with 1000 km^3 class edifice that had formed through 0.1 to 0.2 million years of volcanic activity. This contrasts clearly with the migration of volcanic activity from 5 to 0.7 million years BP in the two regions.

Keywords: Quaternary, caldera, Indonesia, Sunda arc, radiometric dating, mass fractionation correction method