Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SVC52-01 Room:301A Time:May 21 13:45-14:00

Effects of relationship between temperature and melt fraction of crustal rock on magma generation by crustal melting

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Crustal melting by injection of hot magmas is an important process for magma genesis in continental crust. Most magmas in arc magmatism in continental crust like Japan are probably produced by crustal melting. An aim of this study is to understand constraints of composition, amount, and generation timescale of magmas produced by crustal melting due to hot magma injections. So far, we investigated amounts of mafic and silicic magmas and timescale of magma production by crustal melting using a one-dimensional physical model. In the model, it is assumed that crustal rocks have almost linear relationship between temperature and melt fraction (the relationship is referred to be as melt fraction as function of temperature, F(T)). On the other hand, F(T) is not linear in general cases. For example, F(T) of hydrous granite steeply increases without temperature increase near its solidus, while F(T) of hydrous basalt less increases with temperature near its solidus. Thus, F(T) affects amount of magmas generated by crustal melting. We report effects of F(T) on magma generation by crustal melting in this presentation.

The model of crustal melting by Koyaguchi and Kaneko (2000) is followed. When a crust is melted by a hot magma injected into a crust, large heat flux from the convecting injected magma rapidly melts the overlying crust up to the degree of partial melting large enough to convect (~100 yr timescale). After that, the injected magma and convecting region of partially-molten crust decrease in temperature and melt fraction, and hence cease to convect for melt fraction to decrease down to the critical melt fraction where the mixture of solid and liquid cannot convect. At this stage, heat transfer becomes only conductive and slow (>10,000 yr). When a new injection of a hot magma occurs, the above processes repeat. It is considered that hot magmas repeatedly inject at the same level and that no segregation between liquid and crystal occurs in our model. Additionally, effects of water in the hot magma were also taken into account. The hydrous hot magma melts the crust, solidifies itself, becomes saturated in water, and releases free water into the overlying crust.

We carried out calculation for a gabbroic crust that produces magmas by melting and assumed various F(T) of it. Calculation conditions are as follows. Initially, the surface temperature and temperature gradient of the gabbroic crust with 2 wt% water are 0 deg.C and 20 deg.C/km (the initial temperature of the melted is determined by its depth). Injected hot magmas have basaltic composition, the initial temperature of 1250 deg.C, and the initial water content of 2 wt%. Thickness of a single injection of the hot magma is 50 m. the critical melt fraction of convection is assumed as 0.6. In the calculation, we changed the injection depth of the hot magmas (pressure range is between 0.25-1.0 GPa) and injection rate of the hot magmas (2-20 m3/m2ky). The calculations for 300 ky are carried out.

The calculation results indicate that as a rate of increase of F(T) is smaller near the solidus, total amount of melt produced by crustal melting due to a certain amount of injected magmas becomes smaller while amount of melt produced with relatively low degree of partial melting becomes larger. Melts produced with relatively high and low degrees of partial melting are interpreted as mafic and silicic melts, respectively. Therefore, crusts that have a small rate of increase of F(T) near solidus are favorable to produce voluminous silicic magmas.

Keywords: crustal melting, silicic magma, melt fraction, gabbro, physical model

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Upper mantle and basaltic magmagenesis at an arc-arc junction: Chemical spatial variation of mafic rocks in Hokkaido

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Few studies are directly compared the spatial variation of volcanic rock composition and magma-generation processes in the Northeast Japan (NEJ) arc and Kurile arc. Previously, we have clarified the spatial chemical variation of mafic rocks from Hokkaido, which is located at the junction of these two arcs, and indicated that the southwestern part of Hokkaido can be considered as the northern end of the NEJ arc, but the central part of Hokkaido as the southern end of Kurile arc. Unmodified mantle, which refers to a mantle source before a subduction component (SC) addition, beneath the NEJ and Kurile arcs is heterogeneous. Enrichment increases toward the trench side of the NEJ arc and toward the southern side in the Kurile arc. In this study, we discuss the degree of melting (F), SC composition and the transfer process, as well as clarify the difference in magma-generation processes between the NEJ-arc side and Kurile-arc side in Hokkaido.

The $<$1.7Ma mafic rocks from Hokkaido can be divided by their distribution and composition into four volcanic fields: the eastern margin of the Japan Sea (EJS), the southwestern Hokkaido (SWH), the Taisetsu-Tokachi-Shikaribetsu (TTS) and the Akan-Shiretoko (AKS) volcanic field. While ^{143}Nd/^{144}Nd is same among EJS, TTS and SWH, it is higher at AKS. ^{87}Sr/^{86}Sr increases from EJS to AKS to TTS to SWH. EJS shows the highest contents of incompatible elements and the steepest REE pattern. AKS shows the lowest Nb and Ta contents. At the trench side of SWH and AKS, volcanoes contain low K. These trench-side volcanoes also have lower contents of incompatible elements, larger spikes of Pb and Ba, and flatter REE pattern than rear volcanoes. Moreover, trench-side volcanoes in AKS often show a depleted LREE pattern.

In a Nb/Y-Zr/Y diagram, four areas show linear and parallel trends that can be divided into three groups based on location (SWH, EJS and TTS, AKS: in descending order of Nb/Y at similar Zr/Y). This indicates the compositional heterogeneity of unmodified mantle, which cannot be explained by the degree of prior melt extraction from a single mantle source. According to these Nb/Y values at similar Zr/Y, we assume the Enriched-Depleted MORB Mantle (E-DMM), DMM and Depleted-DMM (D-DMM) of Workman and Hart (2005) for SWH, EJS and TTS, and AKS as unmodified mantle composition, respectively. F and prior melt extraction from assumed initial DMM are calculated by the contents of HFS elements that are conservative and not added from SC. The results indicate that the composition of trench-side volcanoes in SWH and AKS can be explained to some extents by prior melt extraction. In this case, AKS trench-side magma is generated from the most depleted mantle source in Hokkaido–a source that is D-DMM with prior melt extraction. Estimated F is 20% for SWH trench side, 12% for SWH rear side, 7~10% for TTS, 7~12% for AKS and 3~12% for EJS.

Using these estimated F, we determine metasomatized mantle source compositions of Hokkaido magma. Pb of a metasomatized mantle source shows positive correlation with F. In Ba, Th and U vs. F diagrams, several positive correlation trends can be recognized: EJS shows the highest trend and SWH and AKS frontal volcanoes show the lowest trend. The trends of TTS and rear-side volcanoes in SWH and AKS are in the middle. These data indicate the variation of SC composition in Hokkaido.

The difference of magma-generation processes between the NEJ-arc side and Kurile-arc side in Hokkaido are recognized as follows. Solute-rich SC is supplied on NEJ-arc side, as in EJS volcanoes, but not on the Kurile arc side. At the trench side in the NEJ-arc side, magma with the highest F in Hokkaido is generated. In contrast, magma at the trench-side of the Kurile-arc side is generated with relatively low F from the most depleted mantle source in this region. Such a feature of magma-generation processes in Hokkaido may reflect differences in mantle-slab geometry and thermal structure between the two arcs.

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Experimental study on magma plumbing system beneath Fuji volcano

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Fuji volcano, largest in volume and eruption rate in Japan, is located at the center of Honshu, where North Amer-ica, Eurasia and Philippine Sea plates meets. Beneath Fuji volcano, subduction of both Pacific and Philippine Sea plates are undergoing. Eruption of Fuji volcano may be related to large magnitude interplate earthquakes at least in some cases. Magma chamber beneath Fuji volcano is considered to be unusually deep compared with other volcanoes in Izu-Mariana arc. Fujii (2007) interpreted that unusual depth of Fuji magma chamber is due to thickened low density granitic crust by collision of Izu peninsula. Because of the significance of Fuji volcano both in tectonic settings and potential volcanic hazard, there are a great number of studies on Fuji volcano. However, studies focused on magma plumbing system beneath Fuji volcano are limited and there are no high-pressure experiments on Fuji basalt so far. The purpose of this study is to determine the conditions of the magma chamber (P, T, fO2, etc) of Fuji volcano through high pressure melting experiments.

Basalt scoria Tr-1 which represents the final ejecta of Hoei eruption in 1707, was adopted as a starting material. Experiments at 4kbar were carried out using an internally heated pressure vessel (HIP-5000) at the Magma Factory. Temperature conditions were 1050, 1100 and 1150?C, and H2O contents were 1.3, 2.7 and 4.7wt.%, respectively. The fO2 was controlled at NNO-buffer. At 4kbar, magnetite is the first liquidus phase and plagioclase is the second liquidus phase and is followed by clino- and orthopyroxene. Compositions of melts at 4 kbar were determined by EPMA analysis of quenched run products. SiO2 content of melt increases with crystallization and is different from silica non-enrichment compositional trend of Fuji basalt.

In order to explain silica non-enrichment differentiation trend of Fuji volcano, Fujii(2007) suggested that ortho-pyroxene may play important role at the deep magma chamber. Experiments at 7 kbar are in progress using another internally heated pressure vessel (HIP-8600) at the Magma Factory. Phase relations and melt compositional trend at 7 kbar will be reported. Based on high-pressure melting experiments and petrologic study, mechanism of Hoei sub-plinian eruption and origin of the dacite which was erupted at the initial stage of Hoei eruption will be discussed.

Keywords: Fuji volcano, magma, Experimental petrology, Subduction zone, High-pressure experiment

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The 1883 eruption of Krakatau and its subsurface structure

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The present discussion is composed of 2 parts: The first part deals with the Verbeek's estimation (1885) of volume of the ejecta from the 1883 Krakatau eruption. Finally a balance sheet between the volume of juvenile material and that of lithic material is drawn. The second part discusses the subsurface structure of the Krakatau complex deduced by gravimetric and seismological methods.

In Part 1, the Verbeek s method is criticized from a viewpoint of methodology: Even evaluation of the errors in his surveys is difficult. Using his original data, the present author revises his estimation of the ejecta volume: For an example, volume of the total ejecta should be revised from 18.2 to 16.6 km^3. And also volume of the lithic material produced by the eruption is estimated at 11 km^3. Further, volume of the caldera deposits is estimated at 5 km^3 by gravity anomaly observed on the caldera. As a whole, a balance sheet between volume of the deposits in the Krakatau area and their sources can be shown with unavoidable ambiguity.

In Part 2, development of geophysical study of the subsurface structure of Krakatau caldera is historically reviewed and discussed:

Yokoyama (1981) measured gravity on Krakatau Islands and assumed caldera deposits of funnel-shape, about 5 km^3 in volume on the base of gravity anomaly. He calls the deposits 'fallback' that is produced by explosions. He did not discuss magma reservoirs because magma reservoir had not been detected definitely and because cavities in the earth crust do not always collapse due to rigidity of the crust. He emphasized gigantic explosivity of the 1883 eruption that caused strong pressure waves simultaneously occurring with the large tsunami.

Harjono et al. (1989) set up 10 temporary seismic stations on the both sides of the Sunda Straits and one on Anak Krakatau, all being equipped with a single vertical seismometer, and examined wave paths from 14 local earthquakes occurring in summer of 1984 and detected two bodies of shear-wave attenuation near the Krakatau complex: one is about 9 km deep directly beneath the Krakatau complex and the other is voluminous and deeper (about 22 km deep at the top) extending towards the SW.

Deplus et al. (1995) got a detailed bathymetry in the caldera area and supplemented gravity survey on land and sea. They interpreted the gravity anomalies observed at the caldera and reached the similar conclusion to Yokoyama's. They assumed the caldera deposits as the collapsed volcano body, not fallbacks and modeled the deposits by various types of cylinder.

Jaxybulatov et al. (2011) carried out temporary seismometric observation at 14 onshore stations on Krakatau Islands (3 on Anak Krakatau) and on the coasts of Java and Sumatra. During about 8 months, more than 700 local earthquakes were recorded, and tomographic inversions for P and S velocities and for the Vp/Vs ratio were performed. They obtained a zone of high Vp/Vs ratio nearly beneath the Krakatau complex though the network configuration and the distribution of the events were not favorable for high quality tomographic imaging. At depths from the surface down to 4 km deep, they observed Vp/Vs ratio higher than 2 and assumed it as a probable indicator of the presence of partially molten material.

The present author attributes the anomalous values of Vp/Vs ratio deduced by Jaxybulatov et al. (2011) to the caldera deposits proposed by Yokoyama (1981) considering the resolution capacity of their tomography in the Krakatau area. A problem should be what is the origin of the caldera deposits. At many calderas in Japan, we have much knowledge on caldera deposits: They are usually fallbacks of low density deposited in funnel-shape.

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Characteristics of a caldera volcano, and process to a caldera-forming eruption in Indonesia

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There are various volcanoes in the world. Almost volcanoes erupted frequently. However, some volcanoes seem to be quite for preparing a large-volume eruption with caldera formation. What is a caldera-forming eruption? Compared with usual eruptions, a caldera-forming eruption, erupted volume˜ 10-1000 km3, causes huge direct damages, wide-spread pyroclastic flow, air fall, lahar, tsunami, and global impacts such as climate change; The recovering time is more than 10 years for climate, ocean, food, human health, traffic, buildings, and 100-1000 years for land use. Japanese have forgotten a caldera-forming eruption, because the last one occurred 7,000 years ago. Indonesia was suffered twice for the last 200 years, and three times within 1000 years. The total victims amount to 130,000, which is 55 % of the total ones from eruptions in the world during the last 200 years.

We have questions on the caldera-forming eruption. (Q1) Can we get a precursor sign for the eruption (where, when, what volume)? (Q2) Is not the eruption infrequent ($<$ once / 100 years)? (3) Can we evaluate the next candidate for hazard mitigation? We carried out the JST-JICA project as follows. The first is to study the process to the caldera forming eruption, that is, the quantitative eruptive history of target volcano to caldera-forming eruption, especially, multi-caldera volcanoes in Bali (Furukawa et al., 2012). (2) The second is to clear the frequency of the caldera-forming eruption, that is, the temporal and spatial distribution of the eruption in East Java and Bali (Toshida et al., 2012). The third (this paper) is to evaluate volcanoes base on the obtained geological data, in order to answer (Q1) and (Q2). The results will contribute to the answer of (Q3).

The short-term evolution: During the last a few months, we may catch the short-term process as the progressive activity to the climax eruption. We compiled the example of Pinatubo 1991 eruption, Philippine (Harlow et al., 1996; Hoblitt ea al., 1996; White et al., 1996; Wolfe and Hoblitt, 1996), that of Krakatau 1883 (Rampino and Self, 1982), that of Tambora 1815 (Junghuhn, 1854; Self et al., 1984, Stothers, 1984; Yamamoto et al., 2000; Takada and Yamamoto, 2008). There occurred a lot of small eruptions and hydrothermal explosions during the last a few months just before the climax. Moreover, there occurred unusual wide-range hydrothermal activity, 2-5 km-wide, before the climax, suggesting the existence of an active large volume magma beneath the summit.

The long-term evolution: There was a large shield or stratovolcano constructed with a large eruption rate before the caldera forming eruption, for example, Tambora, and Tenggar. In contrast with those volcanoes, Kelute has never cause the caldera-forming eruption. The long-term eruption rate is far smaller than those of volcanoes with caldera. The Kelute is composed of several volcanoes with repose periods. Next, we compiled the eruptive histories of caldera volcanoes which were studied as corporation projects between GSJ and VSI: Tambora (Takada et al., 2000; Matsumoto et al., 2000), and Rinjani (Takada et al., 2003; Nasution et al., 2003; Furukawa et al., 2004; Furukawa et al., 2005). We got the scenario that, during the last 10,000 years before the caldera formation, the eruption rate decreased, eruption style changed to more explosive, and chemical composition changed.

Keywords: Caldera-forming eruption, Indonesia, Large-volume eruption, long-term eruption rate, precursor, eruptive history