Numerical simulation of basaltic volcanism in the central Chugoku district, Southwest Japan

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Cenozoic basalts in the central Chugoku district are characterized by a compositional trend that varies gradually from strongly alkaline to subalkaline with a distance from the Japan trench, as well as an exponential increase in the eruption volume from San-yo zone near the subduction to San-in zone in the back arc side [Iwamori, 1989]. Such petrologic trend is opposite to that of typical arc volcanism where the melting is believed to be caused by the subduction of the plate and dehydration of the slab. Melting experiments of the primary magmas in the Chugoku district reveal genetic conditions of the basalts that corresponds to potential temperature of 1300 C [Iwamori, 1991]. At the same time, these experiments suggest that the primary magma is likely to contain water of a few weight %. This estimate is higher that that of 0.1 wt % in MORB. On the other hand, XRF analyses of incompatible elements of the basalts in the San-yo zone show a pattern similar to that of OIB [Iwamori, 1992]. Further, under the central Chugoku district, deep earthquakes are not observed [Shiono, 1982] and therefore it is considered that there is a lack of a slab to prevent mantle from upwelling. Thus these experiments and observations indicate that the volcanism in the Chugoku district is resulted from upwelling of plume that includes significant amount of volatiles [Iwamori, 1992].

Indeed, a simple arithmetic suggests that a small mount of melting of 1 wt % causes buoyancy comparable to that due to temperature anomaly of 50 K. Also, it is well known that an additon of small amount of volatile, in particular water, results in an decrease in melting temperature [cf., Kushiro et al, 1968]. Then, in this study, we aim to evaluate quantitatively by numerical calculations an importance of small amount of melting due to volatiles and behavior of magma on voluminous and high degree of melting in the San-in zone. In order to take into account buoyancy and relative motion between the melt and the matrix, we adopt basic equations of two phase flow proposed by McKenzie [1984], as well as those by Scott [1992]. We assume that the melting temperature decreases in proportion to an average concentration of volatile in the melt and matrix only if the degree of melting is less than 5 %.

We solve a set of two-dimensional steady partial differential equations for various viscosity of the mantle, amount of volatile injected at the bottom boundary, temperature of surrounding mantle, and potential temperature of the plume. First, it is confirmed that voluminous melting occurs for a model with viscosity of the mantle of 1.5 x 10^20 Pa s, potential temperature of the plume of 1340 C, and amount of the volatile at the bottom of 0.5 wt %. When the volatile is not included, the degree of melting is only a few %, at highest. In contrast, when viscosity of the mantle is as low as 0.5 x 10^20 Pa s, voluminous melting occurs for models with potential temperature of the plume of 1340 C and temperature of surrounding mantle less than 1300 C regardless of amount of the volatile. These numerical results suggest that the addition of the volatile plays a crucial role in voluminous and high degree of melting in the San-in zone, only if viscosity of the mantle is higher than an average viscosity of Athenosphere. Thus it is interpreted that small degree of melting due to the addition of the volatile can trigger upwelling of the plume when the mantle viscosity is high, while, when the viscosity is low, solely buoyancy due to small temperature anomaly can cause the plume to ascend to a depth of dry solidus. On the basis of the sea level changes, the viscosity of the mantle beneath Kyushu district that is another part of southwestern Japan arc is estimated to be between 0.8 and 2.0 x 10^20 Pa s [Nakada et al., 1998]. Therefore the volcanism in the Chugoku district is likely to be triggered by the addition of the volatile in the deep part of the mantle.