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Conduit magma convection of a rhyolitic magma: Constraints from cosmic-ray muon radiography of Satsuma-Iwojima, Japan

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The cosmic-ray muon radiography conducted at Satsuma-Iwojima volcano revealed a low density region just beneath the summit crater of Mt. Iwodake, an intensively degassing rhyolitic dome and the low density region is interpreted as vesiculated magma in a conduit. This is the first direct evidence of the conduit magma convection of a rhyolitic magma. We will introduce the conduit magma convection model inferred for the Satsuma-Iwojima volcano and discuss the implication of the density structure obtained by the muon radiography and the constraints to the conduit magma convection model.

Mt. Iwodake of Satsuma-Iwojima is continuously emitting high-temperature volcanic gases with SO2 flux of 1000t/d for more than hundreds of years. The continuous volcanic gas emission requires that the gases are supplied from a deep magma chamber to the surface by the conduit magma convection. The conduit magma convection model recently becomes to be accepted as a reasonable model for basaltic volcanoes, but is not yet well tested for dacitic to rhyolitic volcano, such as Satsuma-Iwojima volcano. Several studies, such as observation of the high-temperature fumarolic gases, volatile contents in melt inclusion etc (Saito et al., 2001), suggested the shallow magma degassing. However, it is not evident that the magma is actively degassing at near-surface beneath the summit crater, where magmatic eruption did not occur more than several hundreds of years, and the conduit magma convection model is required to be proved by more direct evidence.

The muon radiography at Mt. Iwodake revealed that a low density region of 1.8 g/m3 with a 130-m-wide and 140-m-height locates 130 m beneath the summit crater (Tanaka et al., 2009). The observed density is an average density along the muon path through the volcanic edifice. Considering that average density of the volcanic edifice is about 2.0 g/m3, the path length is 1600 m at 210 m beneath the crater floor, and the thickness of the low density region is 200 m, we can estimate the density of the low density region is about 0.5 g/cm3. The low density material is most likely a highly vesiculated magma. There is no other geological material with such a low density which can survive long time under the extremely acid and high-temperature volcanic gas conditions. But the highly vesiculated magma is not stable because of the large gas permeability. In order to maintain the low density region by the vesiculated magma, the vesiculated magma needs to be continuously supplied to replace the degassed magma. Therefore, the low density region beneath the summit crater is an equivocal evidence of the conduit magma convection.

The large viscosity of rhyolitic magma requires a large volcanic conduit for the conduit magma convection. Based on a simple fluid-dynamic model, Kazahaya et al. (2002) estimated that the conduit diameter needs to be larger than 100 m for the magma convection to cause the observed flux of volcanic gases. The 200 m diameter of the low density region agrees well with this estimate. The low density region is significant at near-surface, but becomes unclear at depth deeper than 280 m from the crater bottom. This density increase with depth might be caused by the changes of the distribution of low-density ascending magma and high-density descending magma with decrease of the diameter of the magma ascent flow at depth deeper than 280m. The density structure revealed by the muon radiography provides not only the evidence of the conduit magma convection but also the constraints to the size, shape and flow pattern of the magma convection.