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ビンガム流体モデルに基づく、玄武岩質マグマの粘性率に及ぼす結晶の影響の解析

Analyses of the effects of crystals on viscosity of basaltic magmas based on Bingham fluid model

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Suspended crystals exert two significant effects on viscosity of magmas; one is to increase relative viscosity, a ratio of viscosity of magma to that of silicate melt, and another is to induce non-Newtonian (shear strain rate-dependent) behavior. Bingham fluid model is one of the simplest models of non-Newtonian fluid and is often adapted to approximate rheological properties of crystal-bearing magmas in numerical studies of lava flow behaviors (e.g., flow rate, flow path, morphology). However, our knowledge on relationship between the Bingham parameters (Bingham viscosity and yield strength) and textural characteristics of magma is not enough. The purpose of this study is to understand the relationship quantitatively, and to determine whether the Bingham model or power law fluid model, an another simplest non-Newtonian fluid model, is better to approximate rheological behavior of crystal-bearing magmas. For this purpose, we analyzed our published and newly obtained high-temperature viscometric dataset to extract the Bingham parameters and also compared them with textural characteristics.
In this study we analyzed the shear stress-shear strain rate dataset based on Bingham fluid model for the Fuji 1707 basalt (Ishibashi, 2009, JVGR) and also for another basalt of different compositions (e.g., high-Fe tholeiite erupted at 1778 from Izu-Oshima, Japan). All of dataset analyzed were obtained using the high-temperature concentric cylinder rotational viscometer at Kobe University. Viscosity measurements were performed under conditions of one atmosphere pressure, oxygen fugacity near QMF or NNO buffers, temperatures in the range from ca.+60K to ca.-80K relative to liquidus, crystal fractions lower than ca. 35 vol.%, angular velocity from 50 to 0.3 rpm with 6mm and 30mm diameters of inner rotational and outer fixed cylinders, respectively. After each viscosity measurement, molten sample attaced to the inner rotational rod was quenched and processed to thin sections for quantitative analyses of texture and phase compositions. We determined crystal volume fraction and distributions of size, length/width ratio, and orientation of suspended crystals for each sample, which were compared with viscometric results to discuss about the effects of crystals on flow property of magma.
In the case of the Fuji 1707 basalt, which contains tabular plagioclase crystals with average length /width ratio of ca. 8.5 and its flow property was successfully described as power law fluid (Ishibashi, 2009), its flow behavior was also well approximated by Bingham fluid model. Reproducibility of measured dataset by Bingham fluid model was almost the same as that by power law fluid model. The basalt behaved as Newtonian when crystal fraction, F, is lower than ca. 10 vol.%. Yield strength was observed when F exceeded ca. 10 vol.% and increased exponentially up to ca. 26 Pa with increasing F up to ca. 0.25. Logarithm of yield strength was

proportional to (1-F/0.6) with a factor of ca. ?13. The ratio of Bingham viscosity to viscosity of silicate melt also increased up to ca. 6 as F increased up to 0.25. Logarithm of the ratio was proportional to log (1-F/0.6) with a factor of ca. ?3.5. We think these factors depend on shape factor of suspended crystals. We will perform the same analyses on compositionally different basaltic magmas to examine the crystal shape-dependences of Bingham parameters and to determine whether the Bingham model or power law fluid model is better.

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