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Viscosity change of magmas during crystallization: a summary

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Recent development of viscometry of magmatic suspensions are reviewed, and our experimental works on the subliquidus viscometry on some magmatic systems are summarized. Prof. Hisashi Kuno together with Dr. Tsutomu Murase attended the 1968 Andesite conference in Oregon, convened by Prof. A.R. McBirney, and Prof. Kuno was surely aware of the importance of viscosity of magmas to understand the volcanic and magmatic processes.

Theoretical consideration of Einsten(1906) together with the modification of Roscoe(1952) and Marsh(1981) gave the Einstein-Roscoe-Marsh's equation: $u=u0(1-p/0.6)^{(-2.5)}$, where u, u0, p represent bulk viscosity, viscosity of melt, and crystal fraction, respectively. This equation is useful for estimating rough viscosity of magmas where the crystal contents and melt viscosity can be obtained from the analyses of rock textures, temperature and groundmass compositions. Actually, effect of morphology of crystals (e.g., aspect ratio of oblate or prolate crystals) and dispersion of crystal size distribution may cause the departure from the ERM equation, and the last several years have seen renewed experimental and theoretical works on this topics (e.g., Costa, 2005, 2009; Sato, 2005; Ishibashi & Sato, 2007; Arbaret et al., 2007; Carrichi et a., 2007, 2008; Mueler et al., 2010, Vetere et al., 2007, 2008). These works are mostly based on the ERM equation and extends them to non-Newtonian (shear rate dependence) or high crystal fraction systems.

We installed an atmosphere-controlled furnace available for viscometry, and carried out viscometry and sampling of some magmatic systems. The starting materials we used are, high-Alumina basalt of Fuji volcano, alkali basalt of NW Kyushu,shoshonite from Vulcanello, MORBs, Hawaiian tholeiite, arc basalt from Izu-Oshima Island. The furnace atmosphere are controlled by mixed gas of H_2 and CO_2 under FMQ for MORBs and Hawaiian tholeiite, NNO for alkali basalt, arc basalts and shoshonite. Samples are fused in Pt(Fe saturated) crucible 30mm inner diameter and 60mm high, and ceramic rod of 6mm in diameter is used for torque measurements and sampling. The system is calibrated with standard oil (JS180000) for variations of the depth of the ceramic rod tip and the depth of immersed melt. We firstly melted the samples ca. 50 degree above the liquidus temperatures, and cooled step by step, with measurement and sampling at the end of each step. When the crystal contents reach 14-30 vol.%, the samples are too viscous to measure viscosity and the measurements are terminated. The liquidus phases are plagioclase for the high-Alumina basalt, MORBs and arc basalt, olivine for alkali basalt and Hawaiian tholeiite, and clinopyroxene for shoshonite. Relative viscosity (bulk viscosity over melt viscosity) tends to fit the ERM equation where olivine is the liquidus phase, whereas in systems with liquidus plagioclase or clinopyroxene tend to show larger relative viscosity compared with the ERM equation by a factor of 3-8. The aspect ratio of plagioclase (thin platy) and clinopyroxene (thin prism) in the experimental charges are mostly 5-15, and such large aspect ratio is expected to increase the relative viscosity by strong interaction of crystals (Mueller et al.2010). We analyzed the data for non-Newtonian models of power law fluid or Bingham fluid, and such non-Newtonian effect is obvious for systems with higher crystal contents.

Keywords: magma, viscosity, crystallization, Einstein-Roscoe equation, crystal morphology, non-Newtonian fluid