Thermodynamic simulation of a melt viscosity scale using rhyolite-MELTS program

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Introduction

Melt viscosity is one of the most important physical properties for investigating magma dynamics. Melt viscosity depends on its chemical composition, temperature and water content and many researchers have investigated the relation between melt viscosity and these parameters experimentally; at present, empirical models which describe melt viscosity as a function of these parameters were proposed (e.g., Giordano et al., 2008). On the other hand, Takeuchi (2015) recently showed that melt viscosities calculated from their pre-eruptive conditions of chemical compositions, water contents and temperatures strongly depend on only melt SiO_2 content; the melt viscosity-SiO_2 content relation is called a melt viscosity scale. Takeuchi (2015) discussed that under a control of phase equilibrium at subliquidus temperature, melt water content negatively correlates with temperature at a constant SiO_2 content; the effect of increasing temperature on melt viscosity is counterbalanced by that of decreasing water content. As a result, viscosity of natural melt depends on its SiO_2 content alone regardless of temperature and water content conditions.

Recent advance in thermodynamics of magmatic system enable us to perform a reliable phase equilibrium simulation for melts with compositions similar to natural magmas; one of the most usual and precise models is Rhyolite-MELSTS (Gualda et al., 2012). In this study, we performed phase equilibrium simulation for natural magmas by using Rhyolite-MELSTS to examine reproducibility of the melt viscosity scale under a control of thermodynamic phase equilibrium.

Methods

In this study, isobaric fractional crystallization simulations were performed for a basaltic melt under conditions of pressure of 100, 300, and 500MPa, melt water content of 0.5, 1, and 3 wt.%, and fO_2 ˜ Ni-NiO oxygen buffer. We use the major element compositions of a relatively undifferentiated basalt from Fuji volcano as a starting melt composition. In addition, we applied the equation of Giordano et al. (2008) to the calculated composition-water content-temperature datasets of melts to estimate melt viscosities, η_{melt}.

Results and discussion

The calculated relation between melt SiO_2 content and viscosity is almost consistent with MVS within error of ±0.5 log unit except for runs with initial melt water contents of 0.5 wt.%. Calculated melt SiO_2-viscosity relation for such melts are almost parallel with MVS but they are more viscous relative to MVS even melt H2O content > 2wt.%. We introduce a parameter ΔMVS defied as log η_{melt} −log η_{MVS}, where η_{MVS} is a melt viscosity calculated by MVS. In all runs, ΔMVS increases in the early stage of crystallization and then remains constant or slightly decreases during the later stage. Deviation from MVS for melts with initial H_2O content ˜ 0.5wt.% is attributed to rapid increase of ΔMVS at the early stage of crystallization. In the early stage, DMVS rapidly increases whereas melt SiO_2 content increases only slightly. In addition, both FeO* and TiO_2 contents increase in the early stage whereas they rapidly decrease during the later

stage, indicating that Fe-Ti oxides crystallize in the later stage. Crystallization of Fe-Ti oxides efficiently increases SiO_2 content of residual melt, and hence melt SiO_2 content reflect the change of melt temperature by crystallization/melting of co-existing mineral phases. As a result, a strong correlation is observed between melt SiO_2 content and viscosity. On the other hand, in the early stage of crystallization of basaltic melt, melt SiO_2 content change only slightly with crystallization due to small difference of SiO_2 content between residual melt and crystallized mineral phases. Therefore, melt SiO_2 content does not sensitively reflect the change of melt temperature, resulting in deviation from MVS. Present results may suggest that it is an important criterion for application of MVS that melt SiO_2 content sensitively changes with crystallization, or in other words, difference of SiO_2 between residual melt and co-existing mineral phases is large enough.

Keywords: viscosity, silicate melt, phase equilibrium, MELTS, melt viscosity scale, thermodynamics