Viscosity minimum of lunar high-Ti magma at high pressures and high temperatures

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Viscosity of magma (silicate melt) at high pressure is very important to understand the magmatic processed in the terrestrial planets. The viscosities of terrestrial basalt magmas are relatively well investigated. However, extraterrestrial magmas are not well known. The Apollo 14 black glass is a volcanic glass, which contains the highest amount of TiO2 among the lunar pristine glasses.

Titanium in silicate melt is regarded as a tetrahedrally-coordinated cation (T-cation) at ambient pressure. Because the viscosity change at high pressure is estimated to be affected by the structural change of TO4-network, it is very interesting to know the influence of Ti on the pressure dependence of viscosity. The existence of the viscosity minimum of silicate melts were found in the diopside (CaMgSi2O6)-jadeite (NaAlSi2O6) system (Suzuki et al., 2005). We also showed that the effect of pressure on viscosity depended on the composition. Viscosity minimum at high pressure was also identified in the CAS (Ca3Al2Si6O18) melt (Allwardt et al., 2007). They also carried out 27Al MAS NMR study of glasses quenched from melts at high pressures and suggested that the viscosity minimum was related to the formation of high-coordinated Al. In the case of Ti-bearing silicate melts, Paris et al. (1994) carried out a XANES (X-ray absorption near edge structure) study of K2TiSi4O11 glasses quenched in the pressure range 0.5-3.0 GPa and showed the increase of coordination number of Ti with increasing pressure.

In this study the effect of pressure on molten Apollo 14 black glass was investigated. Viscosity measurement of magma by the falling-sphere method was performed in the pressure range 1.0-3.5 GPa at the Photon Factory, KEK, Tsukuba, Japan. The viscosity was calculated from Stokes' equation. The falling rhenium sphere was observed using an X-ray CCD camera with a YAG:Ce fluorescence screen. Starting material was a synthetic analogue of the Apollo14 black glass, which was categorized to be a lunar high-titanium basalt. The starting composition in weight percent was SiO2=34.00 TiO2=16.40 Al2O3=4.60 Cr2O3=0.92 FeO= 24.50 MnO=0.31 MgO=13.30 CaO=6.90. We used the density data of the molten Apollo 14 black glass measured using the sink/float method by Circone and Agee (1996). The experiments were performed at 1460 and 1530C in the pressure range 1.0-2.3 and 2.4-3.5 GPa, respectively. Under isothermal conditions, viscosity of lunar high-Ti magma decreased to 2.3 GPa and then increased to 3.5 GPa. The viscosity of lunar high-Ti magma may reach a minimum at a pressure about 2.3 GPa. The Apollo 14 black glass is characterized by the high concentration of TiO2. Titanium is known to be the network-former (T-cations) at ambient pressure. Viscosity minimum at 2.3 GPa suggests that the coordination change of titanium occurs in the lunar high-Ti magmas.