

Pressure dependence of the viscosity of lunar magma

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1 Introduction

Viscosity of silicate melt is a fundamental property, which controls many volcanic processes, including rates of melt extraction, ascent, and magma mixing. Therefore, viscosities of various silicate melts have been extensively measured under ambient pressure. However, detailed knowledge about the relation between the pressure dependence of viscosity and the pressure-induced structural change of melt is still insufficient.

Titanium is one of the minor components in terrestrial magmatic liquids. However, titanium is a major constituent of lunar magmas and has a significant influence on the physical properties. 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.

Lunar volcanic rock is characterized by the variety of Ti content. In this study we investigated the viscosity of K₂TiSi₄O₁₁ (KTS4) melt for an analogue material for the lunar magma.

It has been reported that titanium possesses various coordination states (four, five or sixfold coordinated) in silicate liquid depending on the composition, temperature and pressure. Because the viscosity of silicate liquid depends on the degree of polymerization, the coordination change of the network-forming cations under pressure may affect the viscosity change. In this study, the viscosity of melt with KTS4 composition was measured by in-situ falling sphere method at high pressure. The structures of KTS4 glasses quenched from melts at high pressure were investigated using XANES (X-ray absorption near edge structure) spectra by Paris et al. [1].

2 Experimental

A glass with KTS4 composition was synthesized from a mixture of dried powders of reagent grade oxides (SiO₂, TiO₂) and carbonate (K₂CO₃). This mixture was melted at 1200 °C for 5 minutes after the decarbonation for 12 hours at 700°C. To ensure the homogeneity, the grinding and melting was repeated three times.

Viscosity was measured by the falling sphere method on the basis of Stokes' law with the Faxén correction. The falling sphere was observed by using an X-ray camera, and the velocity was measured from the video image. In situ falling sphere experiments have been started using a cubic-type apparatus. It is, however, impossible to measure the radius of container at the experimental

condition, because the transparent X-ray image can be obtained through the gap of tungsten carbide anvils. To measure the inner radius of the container in situ, we chose a Kawai-type apparatus and a molybdenum container. In our experiments we observed the expansion of radius by melting of the sample and the shrinking by quenching. Therefore, it is quite important to measure the inner radius of container in situ to correct the wall effect. An advantage of this method is monitoring the sphere in situ. The experiments were performed at AR-NE7A station at the Photon Factory, KEK, Japan. The settling velocity of a platinum sphere was measured in X-ray images. X-ray diffraction data of a pressure marker was collected by the energy-dispersive method using a pure-Ge solid state detector soon after the observation of the sphere falling. The pressure at the run condition was determined by using the equation of state for MgO.

3 Results and discussion

We observed that the viscosity of KTS4 melt decreased up to 3.3 GPa. However, viscosity increased with increasing pressure above 4.2 GPa. It is known that the height of the pre-edge peak depends on the coordination of oxygen around titanium. On the basis of XANES spectra of KTS4 glasses, Paris et al. [1] showed that the coordination number of titanium increased with increasing pressure. Xue et al. [2] carried out a ²⁹Si NMR study on K₂Si₄O₉ (KS4) glass prepared at high pressure. They showed that the abundance of five- and six-coordinated silicon in the KS4 glass quenched at 4 GPa are only 1.5 and 0.2 %, respectively. Therefore, the formation of higher-coordinated silicon is not expected in KTS4 melt. The viscosity minimum of KTS4 melt between 3.3 and 4.2 GPa suggests that the melt becomes depolymerized by the coordination change of titanium under high pressure.

References

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