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Viscosity of lunar magma at high pressure

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1 Introduction

Viscosity of magma (silicate melt) is a fundamental property, which controls the mobility. Because magma is generated by the melting of rocks in the planetary interiors, the pressure dependence of viscosity is of great interest. Therefore, viscosity of various silicate melts has been measured under high pressure (e.g., [1]).

Titanium is one of the minor components in terrestrial magmas. However, in lunar magmas TiO_2 content varies from less than 1 wt% to about 16 wt%. Lunar magmas are classified into three groups on the basis of TiO_2 content: high-Ti (>9 wt%), low Ti (1.5-9 wt%) and very low-Ti magmas (<1.5 wt%). It has been reported that titanium possesses various coordinated states (four-, five- or sixfold coordinated) depending on the composition, temperature and pressure. Because viscosity of melt is strongly related to the melt structure, it is expected that the pressure-induced structural change affect the viscosity.

We conducted viscosity measurement of two compositions of lunar magma at high pressure. One is a high titanium magma containing 16 wt% of TiO_2. Another is a very low titanium magma containing 0.3 wt% of TiO_2.

2 Experiment

The experiments were performed at the NE7A station by using the MAX-III apparatus. The experimental set-up has been given elsewhere[1]. Viscosity was measured by the falling sphere method on the basis of Stokes' law with the Faxén correction for wall effect. The falling sphere was observed by using an X-ray CCD camera with a TAG:Ce fluorescence screen. The starting materials were synthesized from reagent grade oxides and carbonates. Powders of samples were crystallized under the reduced condition. X-ray diffraction data of the pressure marker (MgO) were collected by the energy-dispersive method using a pure-Ge solid state detector.

3 Results and Discussion

Viscosity of high-Ti magma decreased from 0.4 to 2.4 GPa, whereas increased from 2.4 to 3.4 GPa. Pressure dependence in viscosity can be explained by the structural change in melt. Coordination number of titanium in potassium titanosilicate glasses, which were quenched under high pressure, was investigated using XANES spectra [2]. The average coordination number of titanium was determined to be 4.8 in the glass quenched at ambient pressure. Yarker et al. [3] showed that titanium in potassium titanosilicate glass is five-fold coordinated and forms a square-based pyramid containing one non-bridging and four bridging oxygen. Larsen et al.[4] investigated NMR spectra of ^{17}O in potassium titanosilicate glass prepared at ambient pressure and showed that TiO_5 units are connected to SiO_4 tetrahedra. Although the chemical composition of lunar high-Ti magma is different from potassium titanosilicate glasses, the previous studies in glass structure imply that titanium in high-Ti magma is connected to SiO_4 network at ambient pressure. Paris et al.[2] sowed that the average coordination number of titanium increased to 5.8 at 3.0 GPa. Therefore, six-coordinated titanium may become dominant in lunar high-Ti magma more than 3 GPa. Because oxygen in TiO_6 is non-bridging, the increase in coordination number of titanium implies the modification of network structure in titanosilicate melt. The decrease in viscosity of high-Ti magma from 0.4 to 2.4 GPa is likely related to the modification of network. And the increase in viscosity from 2.4 to 3.4 GPa suggests the completion of coordination change in titanium.

We also measured the viscosity of very low titanium magma at high pressure. We found that the viscosity decreased from 0.8 to 2.6 GPa. In our recent study [5], we showed that the viscosity of terrestrial basalt magma decreased to 4 GPa. We also carried out X-ray diffraction study of the magma at high pressure. The terrestrial magma contains 1.5 wt% of TiO_2 and 16 wt % of Al_2O_3. In aluminosilicate melt at ambient pressure, the coordination number of aluminum is four, and $(Al, Si)O_4$ tetrahedra form network. We suggested that the decrease in viscosity of the terrestrial magma is due to the structural change of AlO_4 tetrahedra at high pressure. Very low titanium magma in this study contains 0.3 wt% of TiO_2 and 7.7 wt% of Al_2O_3. Therefore, the coordination change of titanium is not effective on viscosity. Although the structure of the very low titanium magma has not been investigated, the pressure-induced structural change of AlO_4 tetrahedra is also expected. The decrease in viscosity of the lunar very low titanium magma may be due to the change in network structure at high pressure.

References

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