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地球内部のマグマの理解に向けたケイ酸塩融体の粘性測定

Viscosity measurement of silicate melts towards understanding of the nature of magmas in the Earth

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1. Introduction

Knowledge of the viscosity of silicate melts is important in understanding the nature and dynamics of the magmas in the Earth. In particular, most of the Earth was molten in the early stage of the formation of the Earth (magma ocean), and therefore understanding the nature and dynamics of such magma ocean is important to discuss the formation and evolution of the Earth, as well as other planets.

Silicate melts have a polymerized structure. The degree of polymerization varies mainly by changing SiO_2 content, and as a result, the physical properties such as viscosity significantly change with varying degree of polymerization. There are previous studies for the viscosity of SiO_2-rich polymerized silicate melts, such as those found in current surface volcanoes. On the other hand, silicate melts in the magma ocean of the early Earth are considered to be SiO_2-poor depolymerized melts. However, viscosity of such SiO_2-poor depolymerized silicate melts remain poorly understood, due to experimental difficulties such as high melting temperature, high reactivity, and/or low viscosity. This talk introduces current knowledge and limitation of viscosity measurement of silicate melts by falling sphere viscosity measurement in high-pressure apparatus, and describe perspective on study of silicate melts by electric levitation furnace.

2. Falling sphere viscosity measurement of silicate melts under high pressure conditions

Falling sphere viscosity measurement was developed to investigate viscosities of melts under high pressure and high temperature conditions. The viscosity of melt can be calculated with Stokes' equation by measuring the terminal velocity of a falling sphere in a melt[1)]. The development of synchrotron X-ray imaging allowed monitoring of falling sphere trajectory with time in high-pressure apparatus at in situ high-pressure and high-temperature conditions, which enables us to accurately determined the terminal velocity of the falling sphere and the resultant viscosity of melts.

Figure 1 shows viscosities of some representative silicate melt compositions at high pressures determined by the falling sphere viscosity measurements ($NaAlSi_3O_8$ [2)]; $0.75NaAlSi_2O_6$-$0.25CaMgSi_2O_6$, $0.5NaAlSi_2O_6$-$0.5CaMgSi_2O_6$ [3)]; $CaSiO_3$, $MgSiO_3$ [4)]; Fe_2SiO_4 [5)]). Viscosity of silicate melts strongly depends on SiO_2 content. SiO_2-

rich $NaAlSi_3O_8$ melt has high viscosity of ~2-6 Pa s at 1700 ˚C under high pressure conditions[2]. On the other hand, SiO_2-poor Fe_2SiO_4 melt has markedly low viscosity of ~0.03-0.05 Pa s at the temperature conditions of 1350-1850 ˚C under pressure[5], which is about two orders of magnitude lower than that of SiO_2-rich $NaAlSi_3O_8$ melt. The marked decrease of viscosity of silicate melts with decreasing SiO_2 content is interpreted as due to the increase of number of non-bridging oxygen and decrease of degree of the polymerization in silicate melts.

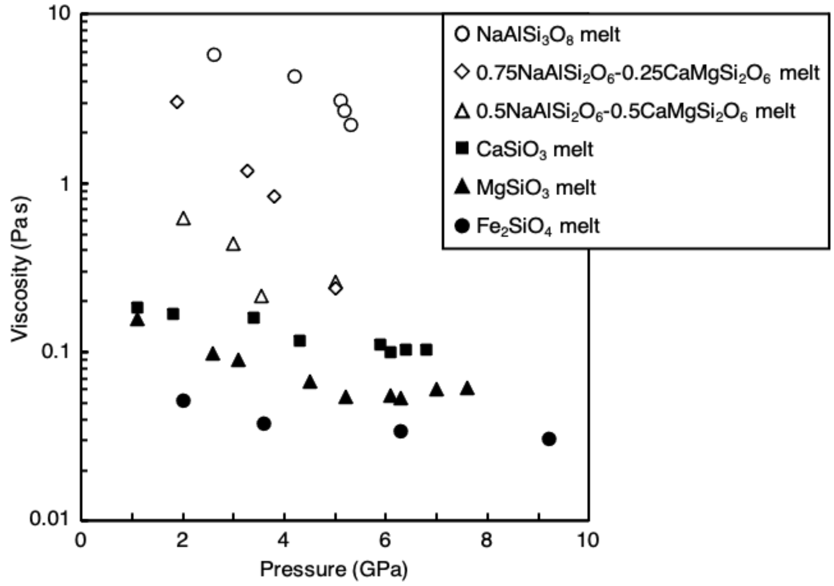

Figure 1. Viscosities of some representative silicate melt compositions as a function of pressure.

3. Limitations of falling sphere viscosity measurement and expectation for electric levitation furnace experiment

Falling sphere viscosity measurement using synchrotron X-ray imaging has enabled us to investigate viscosity of silicate melts under high pressure and high temperature conditions. However, there are two critical limitations: (1) Temperature condition of the falling sphere viscosity measurement is mostly limited at just above the melting temperature, because the probing sphere immediately falls upon melting. Therefore, it is difficult to investigate the temperature dependence of viscosities particularly of SiO_2-poor depolymerized silicate melts having low viscosity by the falling sphere viscosity measurement. In order to discuss the nature and behavior of magmas at very high temperature conditions (e.g. the magma ocean of the early Earth), it is critical to understand the temperature dependence of the viscosity of depolymerized silicate melts far above the melting temperature. (2) It is difficult to investigate viscosity of iron-rich silicate melts, because of high reactivity of iron-rich silicate melts with probing sphere and/or capsule materials.

The electrostatic levitation furnace can melt high-melting-temperature olivine composition (a major component of the Earth's mantle), and it enables us to continuously observe temperature-dependent data. In addition, the containerless method solves the problem of high reactivity of iron-rich silicate melts. The purpose of the Measurement of Temperature Dependence of Viscosity and Density of Depolymerized Silicate Melts (ELF-Silicate Melt) investigation is to determine the temperature dependence of viscosity and density of depolymerized silicate melts with different degrees of SiO_2 content, and different magnesium/iron (Mg/Fe) ratios at high temperatures to supercooled temperature range. The results of the temperature dependence of the viscosity and density of iron-rich silicate melts obtained in the space experiment would provide important information to understand the nature of the magmas in the Earth.

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