

DENSITY MEASUREMENTS OF SILICATE MAGMA UNDER PRESSURE BY X-RAY ABSORPTION TECHNIQUE

Magma, which is generated by the melting of rocks at the deep interiors of the Earth and other planets, is involved not only in volcanism but also in 4.5 billion years evolution of the Earth's and planetary interiors. The ascending or descending migration of magma is driven by buoyant force. Chemical stratification in planetary interior is thought to be formed by the gravitational separation of crystal from magma ocean at the early stage of planetary formation. Density is the primary factor controlling these magmatic processes. However, the density of magma has not been clarified especially at high pressure due to experimental difficulties. Recent advances in synchrotron radiation-based high-pressure and high-temperature technique allow us to approach directly the physical properties of silicate magma, such as structure, viscosity, and density, under high pressure [1]. We introduce, here, the application of the X-ray absorption technique to measure the density of magma under pressure.

High-pressure X-ray absorption technique has been developed for the measurement of the density of a liquid metal by Katayama *et al.* [2]. They confined metallic liquid in a hard sapphire ring and determined its density from the X-ray absorption profile using the Lambert-Beer law $I/I_0 = \exp(-mrt)$ (Fig. 1). It is, however, difficult to apply this method to magma,

because magma is a silicate melt with low X-ray absorption. The high melting temperature (nearly 2000 K) and high chemical reactivity of magma also raise the challenge level of this experimental study. As diamond is the only material that can be used to overcome these difficulties, we use a diamond ring as a sample capsule for magma (Fig. 1). Diamond is X-ray transparent rather than silicate and the hardest material which is uniformly deformed under pressure. The chemical inertness and the extremely high-melting point of diamond also assure the advantage of diamond capsule for X-ray absorption experiments of magma.

It is necessary for high-pressure X-ray absorption experiments to use a multi-anvil high-pressure apparatus generating hydrostatic pressure in a large sample volume (about 0.1 cm³) and a stable brilliant monochromatic X-ray. We choose beamline **BL22XU** wherein a cubic-type press (Fig. 1) and an in-vacuum undulator with a liquid nitrogen cooling monochromator are available. The silicate sample placed in the diamond cylinder and pistons is pressurized to several GPa and heated above its melting point by an internal graphite heater, and then the intensities of the incident and transmitted X-rays (I and I_0) are measured by ion chambers. The X-ray absorption profile (Fig. 2) is surprisingly clear and has

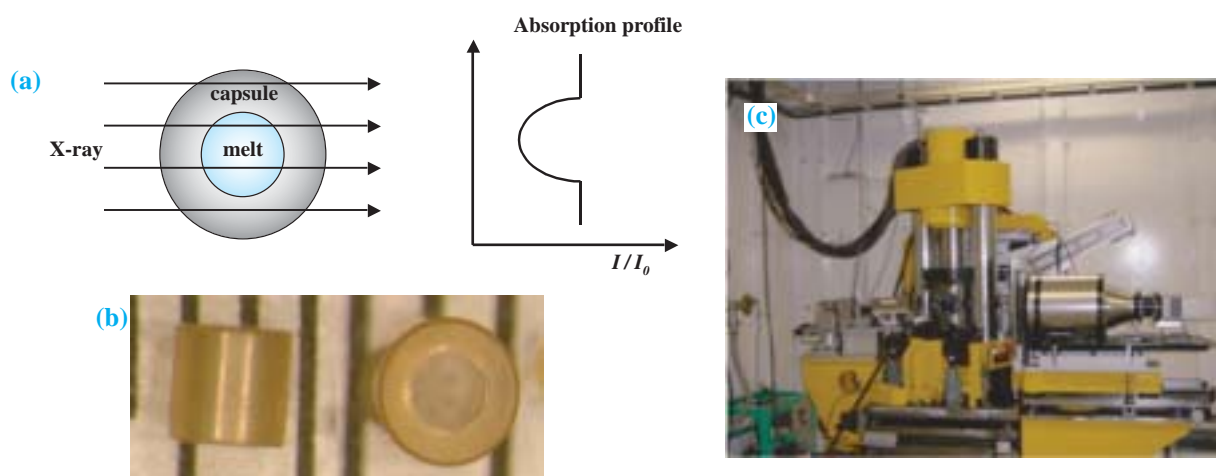


Fig. 1. (a) Concept of high-pressure X-ray absorption technique. (b) Diamond capsule for silicate magma made of synthesized single crystal. (c) Cubic-type high-pressure apparatus SAMP1 installed at BL22XU.

a good quality to yield a density of magma with a meaningful precision, although silicate magma mainly consists of light elements, such as Si, Al, Mg, and O.

Our study on magma density is carried out in two ways: one is to determine the density of simple end-member silicate melt, and the other is the density measurement of natural complex silicate magma. We could determine the isothermal compression curve of basaltic magma, yielding the bulk modulus of basaltic magma with high precision comparable with crystal. Thus, the thermal equation of the state of magma can be evaluated from density measurements. We also study the density of silicate glass at low temperature, which gives an insight into the relationships between the structure and the density of magma. **Figure 3** shows an example of the density variation of $\text{Na}_2\text{FeSi}_2\text{O}_6$ glass with increasing temperature. We can see a clear increase in glass density with temperature at constant pressure, which is the

opposite of the thermal expansion of a common material. This anomalous behavior is an inherent feature of glass and melt, in which their structures change with temperature and pressure. The structure of $\text{Na}_2\text{FeSi}_2\text{O}_6$ glass is expected to change from a low-pressure one into a high-pressure dense one with temperature closing to the glass transition point.

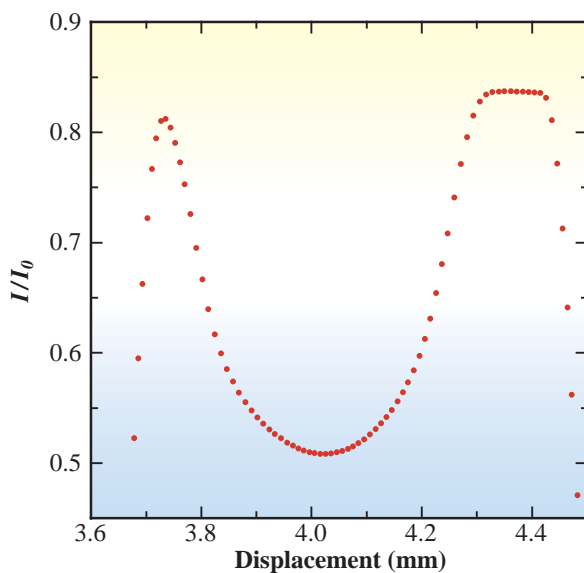


Fig. 2. X-ray absorption profile traversing the radial direction of $\text{Na}_2\text{FeSi}_2\text{O}_6$ melt at 2.5 GPa and 1400 K is obtained by moving the SMAP1 perpendicular to the X-ray beam.

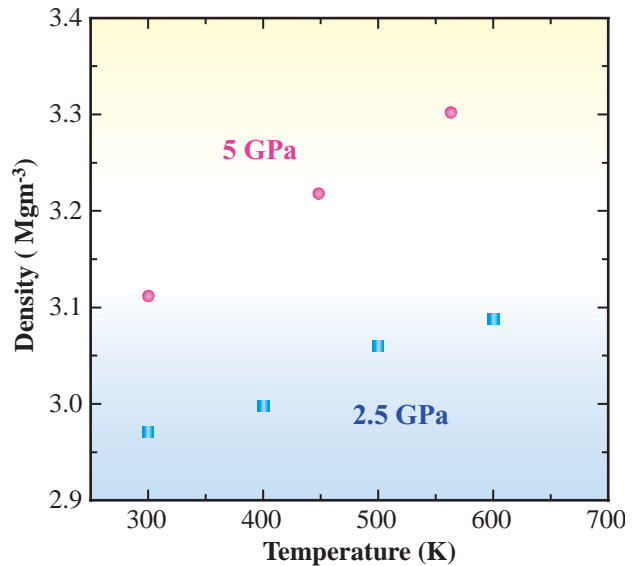


Fig. 3. Densification of $\text{Na}_2\text{FeSi}_2\text{O}_6$ glass at high pressure. This indicates that the structure of glass is relaxed into a high-pressure one by increasing temperature.

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