

Thermal expansion of MgSiO₃ perovskite at the top of the lower mantle conditions

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Introduction

Heat is mainly transported by convection in the Earth's mantle, and therefore the temperature gradient in the mantle should be nearly adiabatic. The adiabatic temperature gradient in the Earth can be expressed as

$$(dT/dz)_s = \alpha g T / C_p,$$

where T is the temperature, z is the depth, g is the gravitational acceleration, and α and C_p are the thermal expansion coefficient and heat capacity at constant pressure of the constituent materials, respectively. The gravitational acceleration can be reasonably estimated from the density. The heat capacity at constant pressure does not change much at high temperatures. Hence knowledge of the thermal expansion coefficients of the mantle minerals is essential when estimating the adiabatic temperature gradient in the mantle.

In situ X-ray diffraction is a practical method for measuring the unit cell volumes of minerals at simultaneous high pressures and high temperatures. However, it is still difficult to determine the unit cell volumes of minerals at very high temperatures by this method because of grain growth. SPEED-Mk.II, the new Kawai-type apparatus that was installed at the synchrotron radiation facility SPring-8, enables us to obtain high-quality diffraction patterns against grain growth [Katsura et al., 2004]. By utilizing this apparatus, we can measure the unit cell volumes of mantle minerals at high P-T conditions corresponding to the deep mantle.

In our previous study, we measured volumes of Mg₂SiO₄ ringwoodite at temperatures from 300 to 2000 K and pressure from 15 to 24 GPa and at a temperature of 300 K and pressure from 0 to 21 GPa, and its thermal expansion coefficient and its temperature and pressure dependencies were determined accurately [Katsura et al., 2004b]. In this study, we try to determine thermal expansion coefficient of MgSiO₃ perovskite with much wider temperature range, that is, 300-2500 K. We also developed technique of pressure generation, which enables us to generate temperature of 2500 K and pressure of 30 GPa simultaneously with WC anvils with 2.5 mm truncated edge length.

Experimental procedure

Starting material is MgSiO₃ enstatite, which was synthesized from tetraethylorthosilicate and Mg metal. It contains small amount of excess SiO₂, suggested by presence of stishovite peaks in the high P-T diffraction patterns. The sample assembly was the same as that used in our previous study [Katsura et al., 2004b]. We used MgO as a pressure standard, and calculated pressure using the equation of state of MgO proposed by Matsui et al. [2000]. See Katsura et al. [2004b] for other details.

We first compressed the sample to 31.3 GPa at ambient temperature, and heated it to 1400 K, where perovskite phase was observed at 26.6 GPa. After that, we conducted compression and decompression between 16 and 30 GPa, and heating and cooling between 300 and 2500 K to obtain volume data at various P-T conditions. The perovskite phase transformed to ilmenite at 2300 K and 21.7 GPa, and the experiment was terminated.

MgSiO₃ perovskite has an orthorhombic symmetry, which shows relatively complex diffraction patterns. In order to determine the cell volumes, we conducted whole powder pattern fitting. In this procedure, we conducted least square fitting with 3 unit cell parameters, intensities of 40-60 perovskite peaks, 5 five background coefficients, and gaussian peak parameters of 3 stishovite peaks for unknown parameters.

Results.

We have obtained thermal expansion coefficient at ambient pressure of $\alpha = 3.2(4) \cdot 10^{-5} + 5.0(2) \cdot 10^{-9} (T-300) / K$. The logarithmic volume dependence of thermal expansion, that is Anderson-Grueneisen parameter is 3.9. The adiabatic temperature gradient at the top of the lower mantle will be 0.45 K/km by assuming the base temperature of 2000 K.