SPring-8

Earth & Planetary Science

KINETICS OF OLIVINE-WADSLEYITE TRANSFORMATION AND PRESENCE OF METASTABLE OLIVINE IN COLD SUBDUCTING OCEANIC PLATES

As the oceanic plate descends into the Earth's mantle, the major constituent mineral olivine $(Mg,Fe)_2SiO_4$ transforms to wadsleyite and ringwoodite at around 400-500 km depths. It has been suggested that these transformations are kinetically inhibited due to low temperatures in the plate and olivine exists beyond the equilibrium boundary as a metastable low-pressure phase producing buoyancy force against subduction [1,2] (Fig. 1). Because the density increase of ~10% caused by these transformations is much larger than the thermal density difference between the plate and
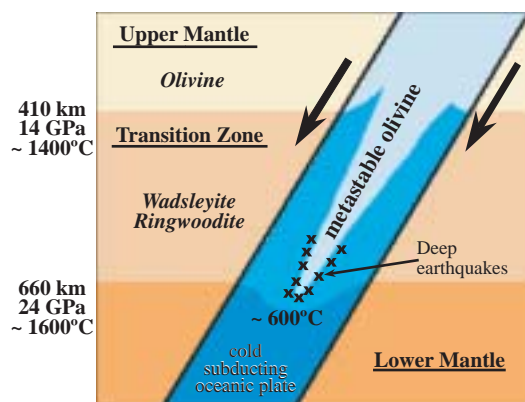

Fig. 1. Schematic illustration showing metastable model of olivine transformation in cold subducting oceanic plate into hot Earth's mantle.

the surrounding mantle, kinetics possibly affects the style of the mantle convection by determining whether cold plates (~600-1200°C) sink into the hot mantle (~1600°C). The presence of the metastable olivine also changes the stress state in subducting plates and is a possible candidate for the origin of deep earthquakes. Thus, to understand the dynamics of the cold current of mantle convection, it is indispensable to examine the kinetics of olivine transformations. The purpose of our study is to estimate the fields of metastable olivine in subducting oceanic plates on the basis of experimentally determined quantitative kinetic data.

It is known that water greatly enhances the rate of olivine transformation [3] and some amounts of water are contained in the Earth's mantle. Therefore, it is needed to determine pressure, temperature and water content dependence on the transformation rate to discuss the transformation rate in the interior of the Earth. We have developed the experimental technique

and directly measured the rate of the olivine-wadsleyite transformation at various pressures, temperatures, and water content conditions [4,5]. High-pressure *in situ* X-ray diffraction experiments have been carried out using the Kawai-type high-pressure apparatus "SPEED-1500" installed in beamline **BL04B1**. The kinetics of the olivine-wadsleyite transformation was observed at 15 different points of 13.4 - 15.8 GPa, 730 - 1100°C, and 660 - 4400 wt·ppm H_2O by time-resolved X-ray diffraction measurements for every 10 - 300 seconds by the energy-dispersive method using a solid-state detector. The concentration of the hydroxyl of the samples was estimated using infrared spectroscopy.

We estimated transformed volume fraction assuming that the relative integrated intensities of the diffraction peak are proportional to the weight fraction of the phase. The time dependence of transformed volume fraction shows that not only temperature but also water greatly enhances the transformation rate (Fig. 2). In the olivine-wadsleyite transformation, the grain-boundary reaction is the dominant mechanism. The results of the fitting of the obtained kinetic data using the Avrami rate equation indicate that the saturation of nucleation site occurs at the initial stage of the transformation and the overall transformation rate is controlled only by growth. In this case, we can estimate the growth rate in the transformation as shown in Fig. 2.
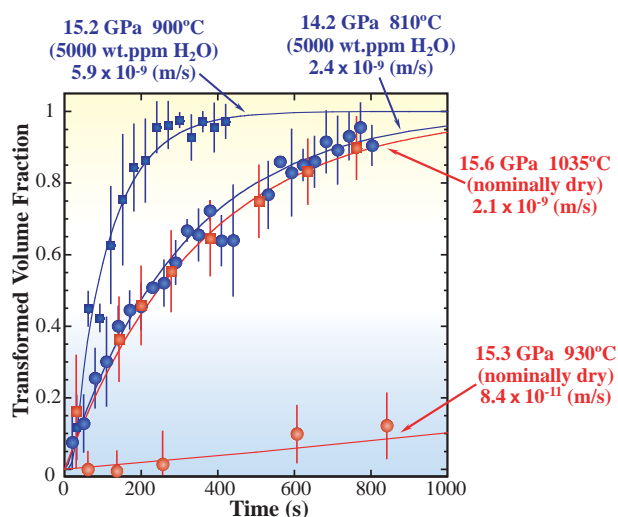

Fig. 2. Time dependence of transformed volume fraction and estimated values of growth rate in olivine-wadsleyite transformation.

Growth in a polymorphic transition is controlled by interface kinetics. The growth rate law can be described as follows;

$$x = ATC_{OH}{}^{n} \exp\left(-\frac{E^* + PV^*}{RT}\right)\left[1 - \exp\left(\frac{-\Delta G_r}{RT}\right)\right]$$

where A is a pre-exponential factor, T is the absolute temperature, C_{OH} is the concentration of hydroxyl, n is the OH content exponent, E^* is the activation energy for growth, P is pressure, V^* is the activation volume for growth, R is the gas constant, and ΔG_r is the free energy change of the transformation. By fitting this rate equation to the growth rate data, pressure, temperature, and OH content dependences on the growth rate were determined as shown in Fig. 3. The results demonstrate that the growth rate in the olivine-wadsleyite transformation is proportional to the OH content to the power of about 3.

Because the depth of the olivine transformation in cold subducting plates is controlled by growth kinetics [2], the effects of water on growth kinetics must be considered to estimate the fields of metastable olivine. We have calculated changes in the depth of the transformation with the OH content in a cold subducting plate on the basis of the growth kinetics determined in this study (Fig. 4). It is clearly shown that the depth of the olivine transformation drastically changes with water content. The metastable olivine can survive greater than the 650 km depths in cold plates containing the water of less than 500 wt·ppm H_2O, which is identical to the depth of the deepest seismicity. Whereas, in cold slabs containing water of 5000 wt·ppm H_2O, the depth of the transformation is reduced to about 450 km depth even in the cold plates. Thus, water would control the field of the metastable olivine and the dynamics of the subducting cold plates.
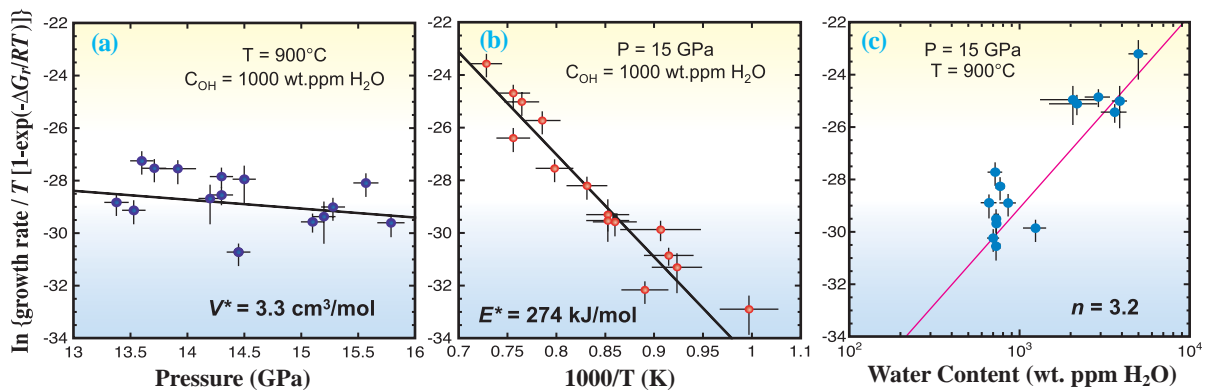

Fig. 3. Pressure (a), temperature (b), and water content (c) dependences on growth rate in olivine-wadsleyite transformation.
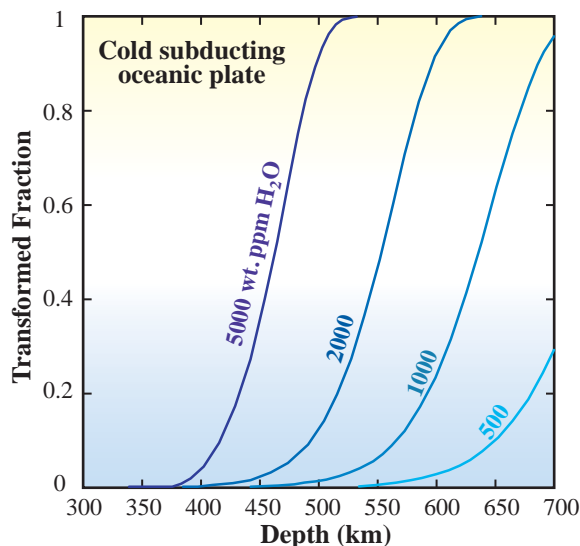

Fig. 4. Depths of olivine transformation with water contents in cold subducting oceanic plate.

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