Defects Speed up the Phase Transition in Olivine

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Introduction

Subducting processes bring olivine, one of the most abundant minerals in Earth's upper mantle, into great depths where its high-pressure polymorphs, wadsleyite and ringwoodite, are stable[1-3]. It is believed that the existence of the metastable olivine characterizes many dynamics phenomena of the Earth, such as deep-focus earthquakes.[4,5] Kinetics of the phase transformation plays a key role in the pressure over step of olivine in the mantle. While the subducting rate dominates the temperature profile of the slab, the characteristic transition temperature from olivine to its high-pressure polymorphs is critical in setting the depth limit of the metastable olivine. If the characteristic transition temperature is higher than the temperature of the cold center of the slab, the slab will consist of metastable olivine. Otherwise, it will be an equilibrium slab.

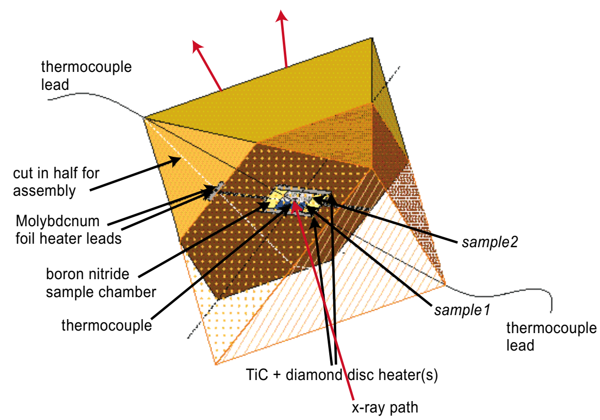

FIG. 1. Assembly for Tcup high-pressure cell. Two samples are embedded in an octahedral pressure medium between heaters.

The time scale in laboratories (minutes to days) is much shorter than geological time scale (millions of years). Phase transformations that happen in the Earth over the geological time scale may not be observed in laboratories. Therefore, finding an effective way to scale down the geological transformation to laboratory experiments is essential for understanding the structure of the subduction slab. Introducing stress in the sample may be one of the solutions.[6] Here we explore another solution: introducing defects in the sample.

Materials and Methods

The starting material in our experiment is San Carlos olivine. The sample is pre-treated by heating at 850ºC in flowing argon gas for two hours. For comparison, a heat-treated sample and an untreated sample are loaded in the sample high-pressure cell in pair (Fig. 1). The samples are compressed into spinel stability field (~16 GPa) at room temperature. Sample temperature is then increased stepwise. The phase transformation is monitored by energy dispersive x-ray diffraction. A thin layer of NaCl is placed between the pretreated and untreated sample as a separator, and also as an internal pressure calibration standard. The sample pressure is obtained by comparing unit cell volume of the NaCl to Decker's scale, and the sample temperature is measured by a W3%Re-W25%Re thermocouple. The *in situ* x-ray diffraction was carried out at the high-pressure station of beamline 13-BM, using the 250-ton LVP.

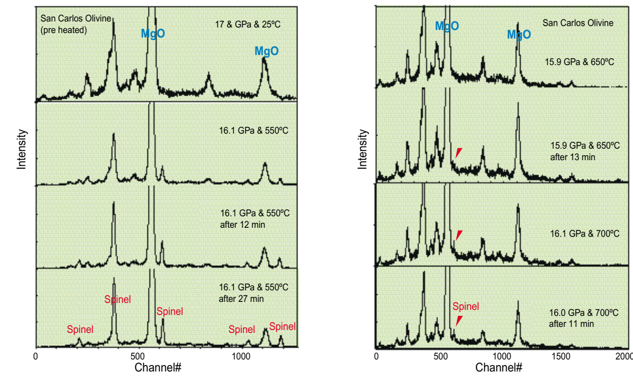

FIG. 2. Diffraction patterns of heat-treated sample (left) and untreated sample (right) at ~16 GPa and different temperatures.

Results and discussion

The heat-treated olivine changes color from green to brownish, indicating a high level of oxidation-related defects in the sample. Figure 2 shows the diffraction patterns of the heat-treated sample and untreated sample at a pressure of about 16 GPa and different temperatures. The olivine-spinel transition is clearly observed at 550ºC in the defective sample, whereas the transformation can be observed only at the temperatures above 650ºC.

The experiment demonstrates that defects in the sample can speed up the phase transition, and therefore lower the characteristic temperature of the transformation in laboratories. Introducing defects, as well as stress, in olivine may be an effective way to scale down the geological time to laboratory time scale. If this is a fair solution in simulating the slab in laboratories, one would expect that the metastable olivine will not survive in the deep transition zone.

Acknowledgments

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