Enhancement of the Kinetics by Orthopyroxene in the Phase Transformations of Olivine to Its High-Pressure Polymorphs

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Introduction

Olivine, with a composition close to $(Mg_{1.8}Fe_{0.2})SiO_4$, is the most abundant mineral in the Earth's upper mantle and reaches more than 80% in the lithospheric mantle due to the extraction of basaltic components from a primitive mantle composition. It has been argued that the transformation of olivine to its high-pressure polymorphs will be kinetically inhibited in the subducted lithosphere where temperature might be as low as 500-600°C at a depth of 400 km. Therefore, olivine might survive as a metastable phase to a greater depth. The olivine metastability has a number of geophysical and geodynamic consequences. Consequently, the kinetics of these phase transformations has attracted great interest in last 30 years. However, the effect of orthopyroxene (opx) on the kinetics of olivine transformation has been generally ignored. As major portion of subducted slab is harzbergitic (that is, olivine and opx are coexisting in the slab, and opx can locally reach as high as 40%), it is necessary to study the kinetics of olivine transformation in the presence of opx.

Materials and Methods

Experiments were carried out at beamline 13-BM. The starting materials included San Carlos olivine and hydrothermally synthesized opx ($En_{90}Fs_{10}$). The powdered samples were dried in a vacuum oven at 160°C for several hours prior to sample loading. Pure opx powder and a mixture of olivine and opx (4:1 volume ratio) were loaded in the same high-pressure cell in one experimental run. Pure olivine powder replaced opx powder in another comparison run. In both runs, two sample layers were separated by powder NaCl (mixed with BN), which was used as the pressure standard. After the sample was compressed to the target pressure (P) using the 250-ton LVP coupled with a T-Cup device, the temperature (T) was increased stepwise. The phase transformations were monitored by x-ray diffraction while the sample assembly remained under the desired P, T conditions. The pressure was calculated based on the Decker's EOS of NaCl, and the temperature was measured by a W-3%Re/W-25%Re thermocouple.

Results

The kinetics of phase transformation of olivine to ringwoodite were greatly enhanced by the addition of synthesized orthopyroxene. The transformation occurred in the mixture of olivine and opx at temperature as low as 450°C (Fig. 1), about 100°C lower than those observed for pure olivine sample in our previous studies. This was also confirmed in the comparison run in which both pure olivine and a mixture of olivine and opx were included in the same cell (Fig. 2). Analysis of opx diffraction patterns for a pure opx sample revealed that opx underwent a phase transformation of its own, namely, opx to high-pressure (HP) clinopyroxene (cpx), upon the increase in temperature.

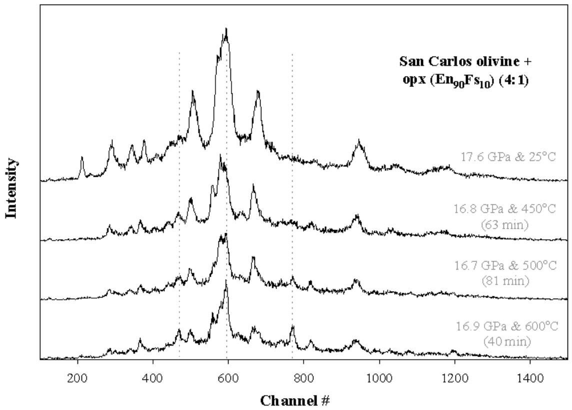

FIG. 1. Sequential diffraction patterns for the mixture of olivine and opx. The transformation of olivine to ringwoodite occurred after about 1 hour at 16.8 GPa and 450ºC. Dotted lines mark the diffraction peaks of ringwoodite.

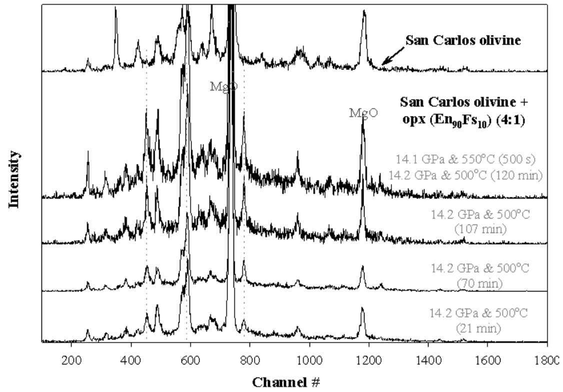

FIG. 2. Diffraction patterns for the mixture of olivine and opx. The transformation of olivine to ringwoodite occurred after about 20 min at 14.2 GPa and 500ºC. No transformation was observed in the olivine sample (top pattern) that experienced the same P, T history as the mixture. Dotted vertical lines mark the diffraction peaks of ringwoodite.

Discussion

The reasons for kinetic enhancement by opx may be threefold. First, additional differential stress can be generated locally in olivine adjacent to opx grain when opx transformed to HP clinopyroxene (about 2-3% volume reduction). The kinetics of olivine transformation is rather sensitive to local shear stress at low temperatures. Second, structures of opx and HP cpx along certain crystallographic directions are very similar to those of ringwoodite and wadsleyite. That is, opx and HP cpx can provide preferred sites for nucleation of high-pressure phases, speeding up the nucleation process. Third, the hydrothermally synthesized opx may contain some fluid inclusions that, upon rupture during cold compression, released significant amount of volatiles to the surrounding olivine samples. It is well known that volatiles can facilitate the solid-state reaction. Future realistic models for the metastability of olivine in the subduction zones must consider the effect of opx.

Acknowledgments

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