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The Olivine-Wadsleyite Phase transformation in Mantle Peridotite

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Beamline(s): X17B1

Introduction: One of the most important goals in studying the olivine (α) – wadsleyite (β) transformation is to understand the now well accepted seismic discontinuity near the depth of 410 km in the Earth's mantle. Although one school of interpretation attributes such a discontinuity to radical chemical changes from Iherzolite to picritic eclogite (Anderson and Bass, 1986), this discontinuity is more widely viewed to be caused by the α-β transformation in an isochemical peridotitic mantle (Ringwood, 1975). If this interpretation is valid, the composition and temperature of the mantle can be inferred at this depth, providing useful information for understanding the present state of the Earth's transition zone. Although there have been many experimental investigations of this transformation, most studies were conducted either using quenching technique (e.g., Katsura and Ito, 1989) or in the simple system Mg_2SiO_4-Fe_2SiO_4. No efforts have been directed to study the kinetic barrier of the olivine-wadsleyite transformation under normal mantle conditions. In addition, recent studies have demonstrated increasing needs for the study of the olivine-wadsleyite transformation in multicomponent systems relevant to the Earth's mantle (Stixrude, 1997; Irifune and Isshiki, 1998).

Methods and Materials: A two-stage multi-anvil press (T-cup) was utilized on the superconducting wiggler beamline X-17B1 of National Synchrotron Light Source. The T-cup has the capacity of generating pressure and temperature up to 18 GPa and 1600 °C.

Peridotite xenoliths brought to the surface in volcanic eruptions or in tectonic uplift have been widely recognized as samples of the Earth's upper mantle. These xenoliths are usually a mineralogic mixture of three major phases: olivine, orthopyroxene, and clinopyroxene. The KLB-1 spinel Iherzolite, a xenolith from Kilborne Hole crater in New Mexico, is chosen as starting material because it represents one of the most undepleted mantle compositions. The powder KLB-1 samples were pre-annealed in the temperature range of 1200-1600 °C at the pressures in close proximity to the α to α + β and α + β to β phase boundaries but outside the α + β loop.

Results: In this work, identifications of the phase transformation were primarily made by observing the first appearance of a phase that does not already exist in the starting sample and by closely monitoring complete disappearance of a phase from the assembly. For a mixture of α + β phases, the transformation was identified by observing a significant change in the relative intensity between the two phases.

The present experimental results have provided a lower bound for the stability field of β phase (β-out) at 1215 °C and an upper bound for the stability field of α phase (α-out) at 1505 °C. In addition, the nucleation barriers determined from reversal experiments at 1300 °C and higher temperatures seem to be about 0.2 – 0.3 GPa for both $\alpha \rightarrow \alpha + \beta$ and $\alpha + \beta \rightarrow \beta$ phase boundaries. From these preliminary data, the width of the two-phase loop appears to be no more than 0.4 GPa. Based on the petrologic barometry and thermometry, the mantle temperatures near the 410-km depth were estimated to be in the range of 1300-1400 °C (e.g., Nisbet et al., 1993). The middle point of these temperatures intersects the two-phase loop determined in this study at pressures of 13.5-13.9 GPa, which is comparable to the pressure of 13.7 GPa at the 410-km seismic discontinuity. This match provides additional confidence in the experimental results that have been obtained.

Conclusions: The results from these pilot experiments demonstrate an experimental feasibility of studying olivine-wadsleyite transformation in complex system and of resolving a pressure difference of less than 0.4 GPa for the two-phase loop, even when the effect of nucleation barrier is taken into account.

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