Phase transformation of hydrous ringwoodite to the lower-mantle phases and the formation of dense hydrous silica

**HUAWEI CHEN**1, **KURT LEINENWEBER**2, **VITALI PRAKAPENKA**3, **MARTIN KUNZ**3, **HANS A. BECHTEL**4, **ZHENXIAN LIU**5, and **SANG-HEON SHIM**1,*

1School of Earth and Space Exploration, Arizona State University, Tempe, Arizona 85287, U.S.A.
2Eyring Materials Center, Arizona State University, Tempe, Arizona 85287, U.S.A.
3GeoSoilEnviroCars, University of Chicago, Chicago, Illinois 60439, U.S.A.
4Advanced Light Source Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, U.S.A.
5Department of Physics, University of Illinois, Chicago, Illinois 60607, U.S.A.

**ABSTRACT**

To understand the effects of H\(_2\)O on the mineral phases forming under the pressure-temperature conditions of the lower mantle, we have conducted laser-heated diamond-anvil cell experiments on hydrous ringwoodite (\(\text{Mg}_2\text{SiO}_4\) with 1.1 wt% H\(_2\)O) at pressures between 29 and 59 GPa and temperatures between 1200 and 2400 K. Our results show that hydrous ringwoodite (hRw) converts to crystalline dense hydrous silica, stishovite (Stv) or CaCl\(_2\)-type SiO\(_2\) (mStv), containing 1 wt% H\(_2\)O together with Brd and MgO at the pressure-temperature conditions expected for shallow lower-mantle depths between approximately 660 to 1600 km. Considering the lack of sign for melting in our experiments, our preferred interpretation of the observation is that Brd partially breaks down to dense hydrous silica and periclase (Pc), forming the phase assembly Brd + Pc + Stv. The results may provide an explanation for the enigmatic coexistence of Stv and Fp inclusions in lower-mantle diamonds.

**Keywords:** Stishovite, ringwoodite, bridgmanite, periclase, water, mantle; Volatile Elements in Differentiated Planetary Interiors

**INTRODUCTION**

Lines of evidence support that the lower mantle has a similar chemical composition to the upper mantle (Kurnosov et al. 2017; Shim et al. 2001a, 2017) that is likely peridotitic or pyrolitic (McDonough and Sun 1995). In a pyrolitic lower mantle, (Mg,Fe)(Al,Si)O\(_3\) bridgmanite (Brd) and (Mg,Fe)O ferropericlase (Fp) are the dominant minerals (Kesson et al. 1996). However, many of the (Mg,Fe)O inclusions do not have similar chemical composition to the upper mantle (Kaminsky 2012). In contrast, numerous studies have documented Stv coexisting with (Mg,Fe)O and Brd (pyroxene with a Brd-like composition) as inclusions in diamonds from the lower mantle (Kaminsky 2012; Litvin et al. 2014; Stachel et al. 2005). Because the pyrolite model cannot explain the coexistence of Stv and (Mg,Fe)O, the diamond inclusions raise an important question about the mineralogy and composition of the lower mantle (Kaminsky 2012). Alternatively, the inclusions may originate from non-pyrolitic sources. For example, Stv can exist with (Mg,Fe)O in a system with a much higher Fe content than pyrolite (Fei et al. 1996). However, many of the (Mg,Fe)O inclusions do not have sufficient Fe for this scenario, and so Brd should be observed instead of Stv in those cases. Experiments have shown that subducted basalt contains Stv together with Brd but not with Fp at the lower-mantle pressure-temperature (\(P-T\)) conditions (Hirose et al. 2005). Therefore, this cannot explain diamond inclusion observations.

An important factor to consider is the possible presence of H\(_2\)O. Studies have shown that minerals in the mantle transition zone can store H\(_2\)O up to a few wt% (Smyth 1994; Hirschmann 2006; Pearson et al. 2014). Indeed, some diamond inclusions indicated the premise that the mantle transition zone is hydrated at least locally (Pearson et al. 2014; Tschauner et al. 2018). However, recent high-pressure experiments have shown very low H\(_2\)O storage capacities for Brd and Fp in the lower mantle (Bolfan-Casanova et al. 2003; Panero et al. 2015). Therefore, H\(_2\)O transport via mantle convection across such a dramatic change in the H\(_2\)O storage capacity at 660 km depth can induce some important changes in the mineralogy of the lower mantle (Schmandt et al. 2014; Tschauner et al. 2018). To understand the effect of H\(_2\)O on lower-mantle mineralogy, we have conducted laser-heated diamond-anvil cell (LHDAC) experiments on a synthetic hydrous ringwoodite (Mg\(_2\)SiO\(_4\) with 1.1 wt% H\(_2\)O; hRw) starting material at pressures between 29 and 59 GPa and temperatures between 1200 and 2400 K, which is expected for the lower mantle.

**EXPERIMENTAL METHODS**

**Starting material**

We synthesized Mg\(_2\)SiO\(_4\) ringwoodite (Rw) from a molar mixture [0.613Mg, SiO\(_2\) + 0.084SiO\(_2\) + 0.167Mg(OH)\(_2\)] of forsterite, SiO\(_2\) (glass), and brucite for...