Phase transformation of harzburgite and stagnant slab in the mantle transition zone

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Subducted materials play an important role in affecting chemical composition and structure of the mantle transition zone. Harzburgite is generally accepted as an important part of subducting slabs, overlain by a layer of basalt. Seismic tomography studies have detected widespread fast anomalies in the mantle transition zone (MTZ) and lower mantle around the circum-Pacific and the Mediterranean region. These anomalies have been interpreted as stagnant oceanic lithosphere materials as these regions are closely associated with subduction zones, where the oceanic lithosphere plunges deeply into the MTZ. However, experimental studies on the phase transformations of harzburgite have been very limited, and no experimental studies have been conducted on the physical properties of harzburgite under MTZ conditions. In this study, we conducted high-temperature and high-pressure experiments, using a 1000-ton Kawai-type multi-anvil apparatus at GPMR, on a natural harzburgite at 14.1-24.2 GPa and 1473-1673 K. At 1673 K, harzburgite transformed to wadsleyite + garnet + clinopyroxene below 19 GPa and further decomposed into an assemblage of ringwoodite + garnet + stishovite above 20 GPa. Some amounts of akimotoite were produced at still higher pressures (22-23 GPa), and finally perovskite and magnesiowustite were found to coexist with garnet at 24.2 GPa. Combining our experimental data with available thermo-elastic properties of major minerals in the earth's mantle and kinematic slab thermal structure analysis, we modeled the velocity and density signatures of the stagnated oceanic slabs in the MTZ under northeast China. We find that a detached harzburgite layer is gravitationally buoyant relative to a pyrolite mantle in the MTZ at depths around 450 and 550 km, below which depths it is negatively buoyant. This buoyancy crossover may have significant dynamical effects. However, the subducting slab remains denser than the surrounding pyrolitic mantle in the MTZ when considering the upper basalt layer. (Slab stagnation is likely governed by a combination of buoyancy, viscosity, and trench retreat.) Relative to a pyrolite mantle, the harzburgite layer also exhibits velocity anomalies which are about 3-5% and 4.5-7.5% fast for Vp and Vs, respectively, in a horizontal layered slab model. While for an undulated slab model, the maximum velocity anomalies are about 2-3% and 3-5% for Vp and Vs, respectively. The velocity anomalies predicted by our slab models are consistent with P-wave velocity anomalies from seismic tomography underneath Northeast China (where comparisons are facilitated by low-pass spatial filtering of our slab models). Our models provide important constraints on the thermal structure, mineralogy, composition, density, and velocities of slab materials in the MTZ.

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