

DENSITY DIFFERENCE BETWEEN SUBDUCTED OCEANIC CRUST AND AMBIENT MANTLE IN THE MANTLE TRANSITION ZONE

Since the beginning of plate tectonics, the oceanic lithosphere has been continually subducted into the Earth's deep mantle for 4.5 Gy. The oceanic lithosphere consists of an upper basaltic layer (oceanic crust) and a lower olivine-rich peridotitic layer. The total amount of subducted oceanic crust in this 4.5 Gy period is estimated to be at least $\sim 3 \times 10^{23}$ kg, which is about 8% of the weight of the present Earth's mantle. Thus, the oceanic crust, which is rich in pyroxene and garnet, may be the source of very important chemical heterogeneity in the olivine-rich Earth's mantle. To clarify behavior of the oceanic crust in the deep mantle, accurate information about density differences between the oceanic crust and the ambient mantle is very important.

We determined pressure-volume-temperature relations (P - V - T equation of state) of related minerals at high-pressure and high-temperature conditions, to precisely evaluate the density difference. Garnet and ringwoodite are the most abundant minerals in the oceanic crust and the ambient mantle, respectively, in the conditions of the mantle transition zone (410 – 660 km deep). However, P - V - T equation of state for the natural compositions of these minerals are not well constrained.

We conducted *in situ* X-ray diffraction experiments at up to 21 GPa and 1273 K, using the SPEED-1500 multi-anvil high-pressure apparatus installed at beamline BL04B1 [1], and simultaneously determined P - V - T equations of state for majorite garnet with oceanic crust composition and ringwoodite with natural Fe-bearing composition. The garnet and the ringwoodite were synthesized from natural abyssal basalt and natural olivine, respectively. These starting materials

were packed separately into NaCl or MgO sample chamber with a mixture of gold and MgO, and compressed in the same high-pressure cell. The pressure was determined by the cell volume for gold using an equation of state of gold [2], and the temperature was measured by a thermocouple. The cell volumes of garnet and ringwoodite were determined by least squares calculations using the positions of X-ray diffraction peaks. The samples were compressed to the desired pressure at room temperature and heated to the maximum temperature to release non-hydrostatic stress.

Pressure-volume-temperature data were collected under 47 different conditions. Figure 1 shows P - V - T data for garnet. The data collected by using an NaCl capsule after heating to above 873 K and the

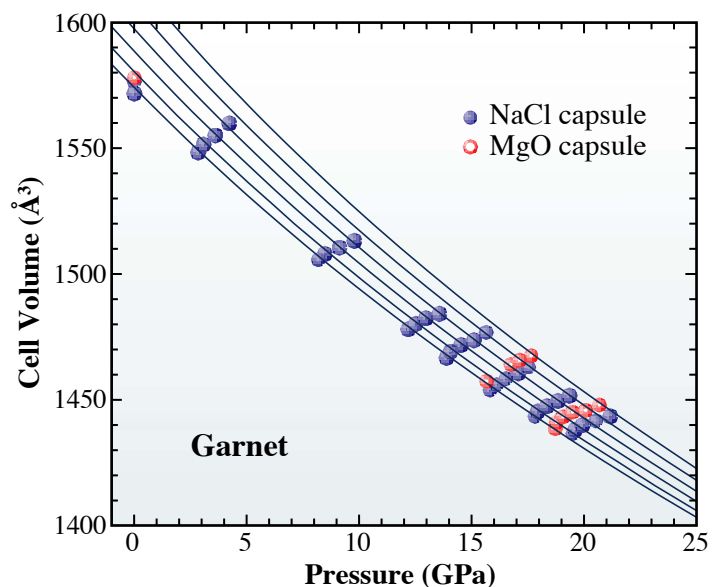


Fig. 1. Pressure-volume-temperature data for garnet with oceanic crust composition with calculated isothermal compression curves. Closed and open circles denote data collected using NaCl and MgO capsules, respectively. The isotherms (from lower cell volumes, 300, 473, 673, 873, 1073 and 1273 K) are fit to high-temperature equation of state.

data collected using an MgO capsule after heating to 1273 K showed consistent results, and the sample conditions are considered to be nearly hydrostatic. Thus, we could determine the P - V - T equations of state for garnet and ringwoodite precisely.

In spite of its high Si, Ca, Fe and Na contents, the present P - V - T equation of state for garnet shows excellent agreement with that of $Mg_3Al_2Si_3O_{12}$ garnet [3,4]. The present equation of state for ringwoodite yields significantly higher thermal expansivity than that derived by diamond anvil experiments on Mg_2SiO_4 ringwoodite to 30 GPa and 700 K [5]. The discrepancy may be due to limited temperature range (700 K at maximum) in the previous study.

The density of oceanic crust and ambient mantle the mantle transition zone were calculated by using present results, previously reported thermoelastic parameters of related minerals and phase relations in oceanic crust and pyrolitic mantle (Fig. 2). Because P - V - T equations of state for garnet and ringwoodite were determined in the same high-pressure experiments, the calculated density difference between the oceanic crust and the ambient mantle in the lower part of the transition zone (520 – 660 km deep) is considered to be valid

even after considering fluctuations in the mantle temperatures, and inaccuracy of pressure determination in the P - V - T experiments, possible error in mineral physics parameters used, etc. Accordingly, the oceanic crust is denser than the ambient mantle across the entire range of the mantle transition zone along geotherms. Present results provide important information for clarifying the behavior of the oceanic crust in the deep mantle.

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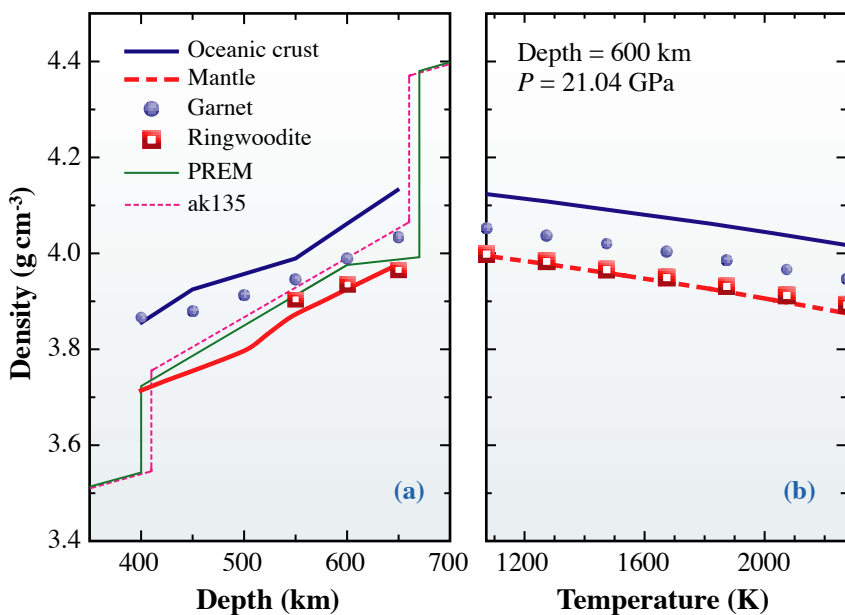


Fig. 2. Density changes in the oceanic crust and the ambient mantle (a) against depth along the geotherm and (b) against temperature at a depth of 600 km (pressure is 21.04 GPa). The bold solid and dashed lines are the oceanic crust and the pyrolitic mantle, respectively. Solid circles and open squares are garnet in the oceanic crust and ringwoodite in the mantle, respectively, which are calculated using present P - V - T equations of state. Seismic observations are shown as thin solid (PREM) and dashed (ak135) lines.