Water Storage Capacity of the Lower Mantle

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Water storage capacity of the lower mantle becomes a matter of debate. Meade et al. (1994) reported 60-70 ppm H2O in MgSiO3-perovskite. However, Bolfan-Casanova et al. (2000) showed absence of water in MgSiO3-perovskite. Murakami et al. (2002) reported 0.1-0.4 wt% H2O in Al-Fe-Mg-perovskite, 0.3-0.4 wt% H2O in Ca-perovskite and 0.2 wt% H2O in ferropericlase measured by SIMS and FTIR. Bolfan-Casanova et al. (2002) reported less 20 ppm H2O in ferropericlase at 25 GPa. Here we report new data on water solubility in Mg-perovskites, Ca-perovskite, and ferropericlase in Al-Fe-bearing systems. Using the measured water content we estimate water storage capacity in the Earth's lower mantle.

The phase relations were determined at 25-26 GPa and the temperature range from 1000 to 1800oC. We used several starting materials corresponding to perovskite and ferropericlase. The hydrous composition was prepared by adding Mg(OH)2 or Ca(OH)2 to the synthetic mineral mixtures and adjusting the proportion of MgO and CaO. The furnace assemblies and experimental details are described by Litasov and Ohtani (2002). Water contents were measured by FTIR. Infrared spectra were measured using Jasco MFT-2000 microsampling FTIR spectrometer (Litasov et al., 2003). The concentrations of hydroxyl groups were determined by the method of Paterson (1982).

IR spectra of pure MgSiO3 perovskite synthesized at 1300oC show bands at 3397, 3423, 3448, and 3482 cm-1. Calculated water content corresponds to about 100 ppm H2O. Al-Mg-perovskite containing 4-7 wt% of Al2O3 shows broad IR spectra with bands at 3404, 3448, and 3565 cm-1. Calculated water content is 1100-1400 ppm. IR spectra of MORB-related Al-Fe-Mg-perovskite synthesized at 1000-1200oC are composed of two major bands at 3125 and 3397 cm-1. The nature of the band at 3125 cm-1 is not clear. We addressed this band to ringwoodite which has major OH vibration band at 3120 cm-1. The water content in MORB-related Al-Fe-Mg-perovskites measured using band at 3397 cm-1 is 90-110 ppm. The unpolarized spectra of peridotite-related Al-Fe-Mg-perovskite, synthesized at 1400-1600oC, composed of two major bands at 3397 and 3690 cm-1. The band at 3690 cm-1 is absent in the spectra of thin crystals and may correspond to quench inclusions of brucite (which has a major band at 3698 cm-1). The H2O content in Mg-perovskite related to peridotite is 1400-1800 ppm.

The unpolarized spectra of aluminous Ca-perovskite (Al2O3=2.0 wt%) synthesized at 1900oC composed of two major bands at 3343 and 3607 cm-1. Preliminary H2O content in Ca-perovskite is near 5100 ppm.

IR spectra of periclase show weak bands at 3299, 3308, and 3404 cm-1. Ferropericlase has major bands at 3299 and 3474 cm-1. Calculated H2O content in periclase is 21 ppm at 1400oC (Al2O3 in periclase is 0.7 wt%) and 112 ppm at 1800oC (Al2O3=1.2 wt%). The H2O content in ferropericlase is 25 ppm at 1400oC (Al2O3=1.0 wt%) and 180 ppm at 1800oC (Al2O3=2.2 wt%). These data indicate that (1) ferropericlase (Mg#=88) contains more water and Al2O3 relative to periclase and (2) water content in ferropericlase increases with increasing temperature and Al2O3.

The present results indicate that Ca-perovskite has highest water solubility among the lower mantle minerals following by Mg-perovskite and ferropericlase. Average fertile lower mantle peridotite consists of 80 wt% of Mg-perovskite, 15 wt% ferropericlase, and 5 wt% of Ca-perovskite. Taking into account possible decrease of water content in the phases with increasing temperature up to the mantle geotherm, we can estimate that the average lower mantle peridotite can contain 0.12 wt% of H2O. Therefore, the maximum amount of water in the lower mantle is estimated as 3.62x1021 kg. This is 2.6 times of the present ocean mass and comparable with the amount of water potentially concentrated in the transition zone.