Water solubility of aluminous post-stishovite at top lower mantle conditions: Implications for water cycle in the deep mantle

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Water is transported into the deep mantle by slab subduction and influences the mantle dynamics and evolution. Discoveries of hydrous minerals in diamonds such as hydrous ringwoodite indicate that the mantle transition zone is a major water reservoir. Although high-water contents in ocean-island basalt imply the presence of water reservoirs in the lower mantle, most minerals in the pyrolitic lower mantle such as bridgmanite and ferropericlase seem to incorporate only limited amounts of water. Basaltic fragments of subducted slabs are thus expected to store water in the lower mantle. In this study, we investigated the stability and water solubility of aluminous silica minerals, stishovite and its high-pressure polymorph with $CaCl_2$-type structure (post-stishovite), which are abundant phases in basaltic crusts subducted into the lower mantle.

Starting materials were mixtures of SiO_2 and AlOOH or $Al(OH)_3$. High-pressure experiments were conducted using multi-anvil presses at 24-28 GPa and 1000-2000˚C. Phase identification of recovered samples was examined by X-ray diffraction. Chemical analyses of recovered samples were performed by electron microprobe analysis and Fourier transform infrared (FT-IR) spectroscopy.

Our results indicate that aluminous post-stishovite is quenchable at 24 and 28 GPa above 1900 and 1700 ˚C, respectively, in contrast to anhydrous aluminous post-stishovite, and can store weight percent levels (1.7-2.1 wt.%) of water. The alumina content increases with increasing temperature and can store up to ~10 wt.%. In contrast to other nominally anhydrous minerals, the water solubility in aluminous post-stishovite increases with temperature because of the increased Al content and higher production of Al^{3+}-H^+ charge coupling. Recent diamond anvil experiments also reported weight percent levels of water in pure SiO_2 stishovite and post-stishovite, but these estimations would have significant uncertainty due to indirect water measurement based on volume expansion. Our study quantitatively estimated the significant water content by a direct water measurement of FT-IR spectroscopy. Hydrous aluminous post-stishovite is stable under most lower-mantle pressure-temperature conditions, including those of plumes, and should thus be the most important water reservoir and carrier in the lower mantle. Hydrous aluminous post-stishovite may further transport hydrogen to the metallic core through subducted slabs.

Keywords: mantle, water cycle, stishovite, post-stishovite, subducting slab

