Volume behavior of the 10 Å phase at high pressures and temperatures, with implications for H₂O content

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ABSTRACT

The 10 Å phase is a hydrous magnesium silicate whose composition appears to depend on synthesis conditions. We have measured the compressibility to 10.5 GPa and thermal expansivity to 400 °C of samples of 10 Å phase synthesized in long experiments (400 and 169 h, respectively) designed to maximize compositional equilibrium. The structure was refined using a metrically trigonal unit cell. Compression is highly anisotropic, especially over the first 2 GPa of compression, indicating weak bonding across the interlayer. There is an inflection in the compression curve of c at 8 GPa, suggesting a change in compression mechanism or the onset of non-hydrostaticity in the pressure medium. Fitting the compression data collected below 8 GPa to a Murnaghan equation-of-state gives \( V_0 = 734.8(7) \, \text{Å}^3, K_0 = 25(1) \, \text{GPa}, K' = 18(1) \). Thermal expansion is also strongly anisotropic: coefficients for data up to 200 °C are \( \alpha_v = 0.15(5) \times 10^{-5} \, \text{K}^{-1}, \alpha_c = 3.1(2) \times 10^{-5} \, \text{K}^{-1}, \alpha_a = 3.4(2) \times 10^{-5} \, \text{K}^{-1} \). Above 200 °C, the expansivity of c decreased, and all parameters showed a contraction after the experiment, suggesting partial dehydration at high temperatures. Comparison of our compressibility data with those of previous studies suggests that 10 Å phase synthesized in short experiments does not retain all of its interlayer H₂O during quenching and decompression. In contrast, samples annealed for many hours at high pressure and temperature are stabilized by small amounts of hydrogarnet-type substitution and consequent hydrogen bond strengthening.

Keywords: 10 Å phase, equation of state, compressibility, expansivity

INTRODUCTION

The 10 Å phase is a hydrous magnesium silicate with a high-pressure, low-temperature stability that means it could play an important role in transporting water into the Earth’s mantle at subduction zones. It was first synthesized by Sclar et al. (1965) at pressures of 3.2 to 9.5 GPa and temperatures between 375 and 535 °C. Its composition and structure are closely related to those of talc, Mg₃Si₂O₅(OH)₂, and it readily forms from the reaction of talc plus water at pressures above ~5 GPa and temperatures up to ~700 °C (Pawley and Wood 1995). Talc is commonly found associated with serpentinites in subducting slabs (e.g., Spandler et al. 2008), where it may transform to 10 Å phase upon subduction, either directly in the presence of excess H₂O, or through the vapor-absent reaction talc = 10 Å phase + coesite + enstatite. Talc may also form in the mantle wedge through metasomatism by silica-saturated fluids released from oceanic crust and sediments of the descending slab (Peacock and Hyndman 1999). The downward drag of the base of the mantle wedge may again lead to the reaction of talc to 10 Å phase as pressure increases. As well as forming from talc, 10 Å phase has been observed to replace chlorite at high pressures in experiments on model hydrated peridotite compositions (Fumagalli and Poli 2005), which should be common in both subducting slab and the overlying mantle wedge. In such compositions, its stability bridges the “choke point” where the stability of the common low-pressure hydrous minerals such as serpentine and chlorite is exceeded but pressures are too low to stabilize higher-pressure dense hydrous magnesium silicates such as phase A and phase E (e.g., Kawamoto 2006).

As well as being important for transporting H₂O deep into the Earth’s mantle, the presence of 10 Å phase will have important implications for mantle rheology and seismic behavior, since it can be expected to behave in a similar way to talc. Talc’s rheologic behavior has been investigated both experimentally and theoretically. Its mechanical weakness (with the lowest possible value of 1 on the Mohs hardness scale) means that even small amounts of talc will affect the strength of talc-bearing rocks, and the presence of talc zones will lead to strain localization during faulting (Escartin et al. 2008). Its soft, platy habit also gives it a very high elastic anisotropy and hence will lead to seismic anisotropy in talc-bearing rocks (Mainprice et al. 2008). Furthermore, both talc and 10 Å phase have been shown experimentally to dehydrate at fast enough rates to trigger intermediate-depth earthquakes (Chollet et al. 2009).

To model the stability of any high-pressure phase in the Earth, knowledge of its equation of state (EoS) is required. In