In situ X-ray observation of 10 Å phase stability at high pressure

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Abstract

The 10 Å phase, Mg$_3$SiO$_4$(OH)$_2$:H$_2$O, is a high-pressure hydrous phyllosilicate considered as an important link in the succession of hydrous phases transporting water into the deep mantle. In this study, in situ synchrotron X-ray diffraction combined with external heating diamond-anvil cell was used to determine limits of the 10 Å phase stability at pressures above 7 GPa. A reaction “10 Å phase + H$_2$O → hydroxide-perovskite (3.65 Å phase) + stishovite” at about 10 GPa was found to be a high-pressure boundary of the 10 Å phase stability field. A dehydration temperature of the 10 Å phase “10 Å phase → enstatite + stishovite + H$_2$O” decreases with pressure from 690 °C at 7 GPa to 450 °C at 10 GPa; a nonvariant point where 10 Å phase, hydroxide-perovskite and enstatite coexist in the presence of stishovite and hydrous fluid was found near 10 GPa and 450 °C.

Keywords: 10 Å phase, 3.65 Å phase, hydroxide-perovskite, DHMS, deep water cycle

Introduction

Several observations, such as electrical conductivity anomalies in the mantle transition zone (MTZ) (e.g., Koyama et al. 2006), seismic evidences of dehydration melting beneath MTZ (Schmandt et al. 2014), or finding of a hydrous ringwoodite inclusion in an ultra-deep diamond (Pearson et al. 2014) convincingly show that MTZ, at least locally, is hydrated. The latter requires an effective mechanism of recycling of surface water to the deep mantle in the cold subduction settings (Ohtani 2015). The most important water reservoir in the subducting slab is serpentinized peridotite (Schmidt and Poli 2014) even along normal subduction (Koyama et al. 2006, 2007). Experimental data suggest that the 10 Å phase is stable in the low-temperature gap between dehydration curves of serpentine and phase A (Fig. 1), and the succession of hydrous phases “serpentine → 10 Å phase → phase A” can retain about 25% of H$_2$O initially stored in the serpentinized peridotite (Schmidt and Poli 2014) even along normal subduction geotherm (Fig. 1).

The dehydration of the 10 Å phase limits its stability field by temperature:

\[
\text{Mg}_3\text{SiO}_4\text{(OH)}_2\cdot\text{H}_2\text{O} \rightarrow \text{3MgSiO}_3\text{(enstatite)} + \text{SiO}_2\text{(coesite/stishovite)} + \text{2H}_2\text{O}. \quad (1)
\]

Pawley et al. (2011) studied this reaction between 5 and 7 GPa (in the coesite stability field) and found that it proceeds at 690 °C independently on the pressure applied. However, at higher pressures the slope of the given reaction has to change because of coesite → stishovite transition.

A low-pressure limit of the 10 Å phase stability corresponds to the reaction 2 taking place at ~5 GPa and studied in situ by Chinnery et al. (1999) and Rashchenko et al. (2016):

\[
\text{Mg}_3\text{SiO}_4\text{(OH)}_2 + \text{H}_2\text{O} \rightarrow \text{Mg}_3\text{SiO}_4\text{(OH)}_2 \cdot \text{H}_2\text{O} \quad (2)
\]

This reaction actually represents an intercalation of water molecules into the interlayer space of talc.