CHEMISTRY AND MINERALOGY OF EARTH’S MANTLE

Electron diffraction determination of 11.5 Å and HySo structures: Candidate water carriers to the Upper Mantle

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ABSTRACT

The dehydration reactions of minerals in subduction zones strongly control geological processes, such as arc volcanism, earthquakes, serpentinization, or geochemical transport of incompatible elements. In aluminum-bearing systems, chlorite is considered the most important hydrous phase at the top of the subducting plate, and significant amount of water is released after its decomposition. However, the dehydration mechanism is not fully understood, and additional hydrates are stabilized by the presence of Al beyond the stability field of chlorite. We applied here a cutting-edge analytical approach to characterize the experimental rocks synthesized at the high pressures and temperatures matching with deep subduction conditions in the upper mantle. Fast electron diffraction tomography and high-resolution synchrotron X-ray diffraction allowed the identification and the successful structure solution of two new hydrous phases formed as dehydration product of chlorite. The 11.5 Å phase, Mg$_6$Al(OH)$_3$(SiO$_4$)$_2$, is a hydrous layer structure. It presents incomplete tetrahedral sheets and face-sharing magnesium and aluminum octahedra. The structure has a higher Mg/Si ratio compared to chlorite, and a significantly higher density ($\rho_0 = 2.93$ g/cm$^3$) and bulk modulus [$K_0 = 108.3(8)$ GPa], and it incorporates 13 wt% of water. The HySo phase, Mg$_6$Al(OH)$_3$(Si$_2$O$_7$), is a dense layered sorosilicate, [$\rho_0 = 3.13$ g/cm$^3$ and $K_0 = 120.6(6)$ GPa] with an average water content of 8.5 wt%. These phases indicate that water release process is highly complex, and may proceed with multistep dehydration, involving these layer structures whose features well match the high-shear zones present at the slab-mantle wedge interface.

Keywords: Subduction, MASH system, electron diffraction tomography

INTRODUCTION

The knowledge of upper-mantle mineralogy is necessary for the understanding of geophysical, petrological, and geochemical processes occurring at inaccessible depths within the Earth (Fumagalli and Klemme 2015). Subsolidus phase relations at subduction zones are of particular interest as they involve hydrates as major characters of the deep water cycle of our planet.

In the past decades, a significant effort was devoted to the recognition of hydrous phases in several compositional systems from the most simple (MgO-SiO$_2$-H$_2$O MSH, MgO-Al$_2$O$_3$-SiO$_2$-H$_2$O MASH) to more complex chemical systems approaching natural bulk rocks of mainly mafic and ultramafic affinities expected to be representative of the input lithologies likely subducted.

The MSH system has been widely used as a reference for the hydrated mantle and the identification of a bunch of hydrous phases, called dense hydrous magnesium silicates (DHMS) (Ohtani et al. 2000; Angel et al. 2001) stable beyond the serpentine and talc stability fields enrolled them as relevant water carriers at depth exceeding 100–150 km, e.g., phase A (Bose and Ganguly 1995) or 10 Å phase (Fumagalli et al. 2001). The MASH system has been widely used as a proxy not only of hydrated mantle rocks but also for hybrid rocks formed as a result of mass transfer at slab-mantle interface in subduction environments. Chlorite is the major relevant hydrate that has been extensively investigated in the MASH system as the major water carrier at mantle depth. Several additional Al-bearing hydrous phases of the MASH system and in more complex peridotite systems are stable beyond its stability field, e.g., the HAPY phase and the 11.5 Å phase (Fumagalli et al. 2014), or the Al-bearing 10 Å phase (Fumagalli and Poli 2005) and more recently it was claimed a new Al-bearing hydrous phase (called 23 Å) stable beyond the stability field of phase A (Cai et al. 2015). The stability field of hydrous phases is traditionally investigated by high-pressure experiments. While extensive technological innovation leads to significantly improved efficiency in generating high and ultra high pressure by means of solid media type multi-anvil apparatus, the obtained run products consist necessarily of nano-grained multi-phase materials, often of inaccessible size for conventional X-ray techniques. The complete characterization of high-pressure charges (i.e., identification and structure determination of all phases present in the sample) is, however, desirable as a complete knowledge of all potential candidate phases stable at variable pressures, temperatures, and chemical...