Strain-induced partial serpentinization of germanate olivine with a small amount of water

SANDO SAWA1,*, NOBUYOSHI MIYAJIMA2, JUN MUTO1, AND HIROYUKI NAGAHAMA1

1Department of Earth Science, Tohoku University, Sendai 980-8578, Japan
2Bayerisches Geoinstitut, University of Bayreuth, Bayreuth 95440, Germany

ABSTRACT

Antigorite, a high-pressure polymorph of serpentine, is considered to be the most abundant hydrous mineral in subduction zones. Although antigorite dehydration is presumed as one of the origins of intermediate-depth earthquakes in the subduction zone, the amount of antigorite is uncertain because the amount of water infiltrated into the oceanic lithosphere is still debated. To investigate whether antigorite can be formed even with limited water availability, we conducted the axial deformation experiments of magnesium germanate at 1.2 GPa and T = 500–800 °C using a Griggs-type deformation apparatus. Magnesium germanate is an analog material of magnesium silicate, and the starting material was dried prior to experimentation. Nevertheless, the samples had initially high porosity, and hence a small amount of water (about 200 ppm wt H2O) was retained in the samples. In the samples deformed at 600 °C, stable slip occurred, and TEM analysis revealed that fine-grained platelets of germanate antigorite existed along the faults. A sharp absorption band assigned to the OH-stretching vibration of antigorite in Fourier transform infrared spectroscopic (FTIR) analysis also implies that antigorite was formed in the samples deformed at a temperature lower than 600 °C. Our results indicate that strain-induced hydration of germanate olivine results in antigorite formation even with only a small amount of water present. Thus, partial serpentinization in the oceanic lithosphere can occur under slight water infiltration due to the high strain accumulated by subduction.

Keywords: Antigorite, serpentinization, subduction zone, TEM, Griggs-type deformation apparatus

INTRODUCTION

Olivine, (Mg, Fe)2SiO4, and its high-pressure polymorphs are the most abundant minerals in the upper mantle (Irifune and Ringwood 1987). Therefore, these magnesium silicates play an important role in mantle theory. However, deformation experiments under the stability field of high-pressure polymorphs of magnesium silicates have been difficult to perform until recently (Kawazoe et al. 2016). Because the olivine phase of magnesium germanate can undergo the phase transformation to the spinel phase at lower pressures than that of magnesium silicate (Ross and Navrotsky 1987), magnesium germanate has been used as an analog material of the magnesium silicate (e.g., Vaughan and Coe 1981; Green and Burnley 1989; Schubnel et al. 2013; Shi et al. 2015; Wang et al. 2017).

Olivine also undergoes a metamorphic transformation to serpentine minerals (lizardite, chrysotile, and antigorite) by a hydration reaction. Serpentine minerals contain 12.3 wt% water and are a great carrier of water into the interior of the Earth (e.g., Evans et al. 2013). In particular, antigorite, a high-temperature polymorph of serpentine, is the most common hydrous mineral under temperatures of 300–650 °C and up to 6 GPa, covering a wide range of subduction zone conditions (Hacker et al. 2003). Antigorite has different physicochemical and rheological properties from olivine, so it has a strong influence on deformation partitioning and seismicity in the subduction zone (e.g., Hirauchi et al. 2010). The faulting associated with the dehydration of antigorite has also been considered as a candidate to explain the intermediate-depth earthquakes (e.g., Raleigh and Paterson 1965; Hacker et al. 2003; Yamasaki and Seno 2003; Ferrand et al. 2017).

Large and deep normal faulting at the outer rise after a megathrust earthquake could enhance the infiltration of fluids into the deep lithospheric mantle (e.g., Obana et al. 2012). Therefore, the peridotite in the oceanic lithosphere is considered to be hydrated (serpentinized) adequately (e.g., Ranero et al. 2003). Meanwhile, elevated pressures prevent water infiltration along the faults (Korenaga 2017). Hence, the amount of antigorite is predicted to be small deeper in subduction zones (Shillington et al. 2015; Korenaga 2017) or rare (Reynard et al. 2010). Therefore, it is important to investigate whether antigorite can be formed even under the limited availability of water in the oceanic lithosphere.

Although many previous studies of serpentinization have been conducted as hydrothermal experiments under excess water (e.g., Martin and Fyfe 1970; Okamoto et al. 2011; Oyanagi et al. 2017) or a large amount of water (Malvoisin et al. 2012; Nakatani and Nakamura 2019), no experiments have been done in the presence of the small amounts of water. Furthermore, magnesium germanate has been the subject of many studies concerning olivine and spinel phases (e.g., Dachille and Roy 1960), but germanate serpentine was only reported by Roy and Roy (1954), Nesterchuk et al. (1984), and Ropp (2013). In this study, to reveal the formation of germanate serpentine under a small amount of water, we first eliminated excess water in the magnesium germanate sample by heating and then conducted...