Effect of structural water on the elasticity of orthopyroxene

MINGQIANG HOU1,2†, WEN-YI ZHOU1,2†, MING HAO1,2‡, FLORIAN TIAN-SIANG HUA3, JENNIFER KUNG3, DONGZHOU ZHANG4,5, PRZEMYSLAW K. DERA4, and JIN S. ZHANG1,2,‡

1Institute of Meteoritics, University of New Mexico, Albuquerque, New Mexico 87131, U.S.A.
2Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131, U.S.A.
3Department of Earth Sciences, National Cheng-Kung University, Tainan City, Taiwan 701, Taiwan
4Hawaiʻi Institute of Geophysics and Planetology, University of Hawaiʻi at Mānoa, 1680 East-West Road, Honolulu, Hawaiʻi 96822, U.S.A.
5Center of Advanced Radiation Sources, University of Chicago, Chicago, Illinois 60637, U.S.A.

ABSTRACT

As a major nominally anhydrous mineral (NAM) in the Earth’s upper mantle, orthopyroxene could host up to several hundred parts per million H2O in its crystal structure and transport the H2O to the deep Earth. To study the effect of structural H2O on the elasticity of orthopyroxene, we have measured the single-crystal elasticity of Mg1.99Si0.01Al0.99O2Si1.95O1.95 with 842–900 ppm H2O and 1.64 ± 0.20 wt% Al2O3 at ambient conditions using Brillouin spectroscopy. The best-fit single-crystal elastic moduli (Cij) of the hydrous orthopyroxene were determined as: C11 = 235(2) GPa, C12 = 173(2) GPa, C33 = 222(2) GPa, C44 = 86(1) GPa, C55 = 82(1) GPa, C66 = 75(3) GPa, C13 = 67(2) GPa, and C12 = 49(2) GPa, with 842–900 ppm H2O and 1.64 ± 0.20 wt% Al2O3. Systematic analysis based on the results presented in this study suggests that the incorporation of 842–900 ppm H2O would increase C11 by 12.0(7)% and decrease C33 by 8.6(8)%.

Keywords: Elasticity, orthopyroxene, structural water, seismic velocities

INTRODUCTION

Water, in the form of structural H2O or free H2O, is transported into the deep Earth’s interior primarily via subduction. As an abundant minor component of water (H2O) in the Earth’s structure, NAMs contain a small amount of structural H2O in the form of hydrous oxides. In its crystal structure, and transport the H2O to the deep Earth. Structural H2O significantly impacts the ionization of dislocation motion, electrical conductivity, phase transitions, melting temperature, and viscosity of mantle minerals (Costa and Chakraborty 2008; Demouchy and Bolfan-Casanova 2016; Jacobsen et al. 2010; Yoshino et al. 2005, 2015; Ohtani et al. 2004). In particular, recent studies have suggested that the presence of structural H2O can result in some observable seismic signatures in the deep Earth (Kong et al. 2020; Van der Meijde et al. 2003; Yuan and Beghein 2013). Consequently, evaluating the effect of structural H2O on the elastic properties of NAMs is crucial to understand the seismic structure, volatile recycling, and mantle mineralogy in the deep Earth (e.g., Ni et al. 2017; Ohtani 2015; Ohtani et al. 2004).

The Earth’s pyrolic upper mantle is primarily composed of olivine, orthopyroxene, clinopyroxene, and garnet. The effects of structural H2O on the elasticity of olivine and its high-pressure polymorphs have been extensively studied (Buchen et al. 2018; Inoue et al. 1998; Jacobsen et al. 2008; Kavner 2003; Mao et al. 2008, 2011, 2012; Schulze et al. 2018; Zhou et al. 2021, 2022). It was suggested that the presence of 1 wt% structural H2O in the olivine polymorphs could reduce seismic velocities up to ~2.5% (Inoue et al. 1998; Jacobsen et al. 2008; Mao et al. 2008, 2011, 2012) and enhance the S-wave splitting anisotropy (Inoue et al. 1998; Jacobsen et al. 2008). However, recent studies showed that high pressure would suppress the effect of structural H2O and the hydration-induced reductions of sound velocities vanish at transition zone pressure-temperature conditions (Buchen et al. 2018; Schulze et al. 2018; Zhou et al. 2021, 2022). Moreover, the effects of structural H2O on the elastic properties of the NaAl bearing-clinopyroxene, and garnet were found to be negligible at room-temperature condition (Fan et al. 2019; Mans et al. 2019). Although the orthorhombic orthopyroxene is the second most abundant mineral in the pyrolic upper mantle, there has been no report about the effect of structural H2O on its single-crystal elastic properties to date.

Compared with olivine, H2O preferably partitions into orthopyroxene at depth above ~300 km in the upper mantle...