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Elasticity of single-crystal Fe-enriched diopside at high-pressure conditions: Implications for the origin of upper mantle low-velocity zones

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Abstract

Diopside is one of the most important end-members of clinopyroxene, which is an abundant mineral in upper-mantle petrologic models. The amount of clinopyroxene in upper-mantle pyrolite can be ~15 vol%, while pyroxenite can contain as high as ~60 vol% clinopyroxene. Knowing the elastic properties of the upper-mantle diopside at high pressure-temperature conditions is essential for constraining the chemical composition and interpreting seismic observations of region. Here we have measured the single-crystal elasticity of Fe-enriched diopside ($Di_{80}Hd_{20}$, Di-diopside, and Hd-hedenbergite; also called Fe-enriched clinopyroxene) at high-pressure conditions up to 18.5 GPa by using in situ Brillouin light-scattering spectroscopy (BLS) and synchrotron X-ray diffraction in a diamond-anvil cell. Our experimental results were used in evaluating the effects of pressure and Fe substitution on the full single-crystal elastic moduli across the Di-Hd solid-solution series to better understand the seismic velocity profiles of the upper mantle. Using the third- or fourth-order Eulerian finite-strain equations of state to model the elasticity data, the derived aggregate adiabatic bulk and shear moduli (K_{S0}, G_0) at ambient conditions were determined to be 117(2) and 70(1) GPa, respectively. The first- and second-pressure derivatives of bulk and shear moduli at 300 K were $(\partial K_S/\partial P)_T = 5.0(2)$, $(\partial^2 K_S/\partial P^2)_T = -0.12(4)$ GPa^{-1} and $(\partial G/\partial P)_T = 1.72(9)$, $(\partial^2 G/\partial P^2)_T = -0.05(2)$ GPa^{-1}, respectively. A comparison of our results with previous studies on end-member diopside and hedenbergite in the literatures shows systematic linear correlations between the Fe composition and single-crystal elastic moduli. An addition of 20 mol% Fe in diopside increases K_{S0} by ~1.7% (~2 GPa) and reduces G_0 by ~4.1% (~3 GPa), but has a negligible effect on the pressure derivatives of the bulk and shear moduli within experimental uncertainties. In addition, our modeling results show that substitution of 20 mol% Fe in diopside can reduce V_P and V_S by ~1.8% and ~3.5%, respectively, along both an expected normal mantle geotherm and a representative cold subducted slab geotherm. Furthermore, the modeling results show that the V_P and V_S profiles of Fe-enriched pyroxenite along the cold subducted slab geotherm are ~3.2% and ~2.5% lower than AK135 model at 400 km depth, respectively. Finally, we propose that the presence of Fe-enriched pyroxenite (including Fe-enriched clinopyroxene, Fe-enriched orthopyroxene, and Fe-enriched olivine), can be an effective mechanism to cause low-velocity anomalies in the upper mantle regions atop the 410 km discontinuity at cold subudcted slab conditions.

Keywords: Fe-enriched diopside, Single-crystal elasticity, Brillouin light scattering, high pressure, Low-velocity zone, 410 km discontinuity