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Elastic wave velocities in polycrystalline $Mg_3Al_2Si_3O_{12}$-pyrope garnet to 24 GPa and 1300 K

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Abstract

The mantle transition zone, at depths between 410 to 660 km, is characterized by two prominent discontinuities in seismic-wave velocity in addition to a relatively steep velocity gradient. Throughout this region garnet will be an abundant mineral, the composition of which will change depending on both depth and lithology. It is important, therefore, to be able to characterize the effects of these changes on seismic velocities, which means that models must incorporate reliable elasticity data on the dominant mineral end-members that can be accurately employed at mantle conditions.

In this study elastic wave velocities of synthetic polycrystalline pyrope garnet ($Mg_3Al_2Si_3O_{12}$) have been measured using ultrasonic interferometry combined with energy-dispersive synchrotron X-ray diffraction in a 1000-ton multi-anvil press. Measurements were performed at pressures up to 24 GPa, conditions compatible with the base of the transition zone, and at temperatures up to 1300 K. Least-squares refinement of the ambient-temperature data to a third-order finite strain equation yields values for the bulk and shear moduli and their pressure derivatives of K_{S0} = 172.0 ±1.6 GPa, G_0 = 89.1 ±0.5 GPa, $\delta K_S/\delta P$ = 4.38 ±0.08, and $\delta G/\delta P$ = 1.66 ±0.05. The determined temperature derivatives are $\delta K_S/\delta T$ = –17.8 ±2.0 MPa/K and $\delta G/\delta T$ = –7.9 ±1.0 MPa/K. High-temperature data were fitted to extract parameters for a thermodynamic model. As several high-pressure and -temperature studies have been performed on pyrope, fitting all of the available data provides a more robust assessment of the accuracy of velocity measurements and allows the uncertainties that are inherent in the various methodologies to be realized. When this model is used to determine pyrope velocities at transition zone conditions the propagated uncertainties are approximately 1.5 and 2.5% for v_p and v_s, respectively. To reduce these uncertainties it is important not only to measure velocities as close as possible to mantle temperatures but also to understand what causes the difference in velocities between studies. Pyrope v_P and v_S at mantle transition zone conditions are found to be approximately 2.4 and 3.7%, respectively, larger than recent determinations of majoritic garnet at the same conditions, implying a significant variation with chemistry that is mainly realized at high temperatures.

Keywords: Elasticity, pyrope, equation of state, synchrotron radiation, ultrasonic interferometry