Elastic wave velocities in polycrystalline Mg$_3$Al$_2$Si$_3$O$_{12}$-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$_3$Al$_2$Si$_3$O$_{12}$) 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 $K_0 = 172.0 \pm 1.6$ GPa, $G_0 = 89.1 \pm 0.5$ GPa, $\delta K_0/\delta P = 4.38 \pm 0.08$, and $\delta G/\delta P = 1.66 \pm 0.05$. The determined temperature derivatives are $\delta K_0/\delta T = -17.8 \pm 2.0$ MPa/K and $\delta G/\delta T = -7.9 \pm 1.0$ 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

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**INTRODUCTION**

Experiment-based models for the mineralogy of the mantle indicate that garnet is a major constituent of both the upper mantle and transition zone, and its stability extends into the top 100 km of the lower mantle (Anderson and Bass 1984; Irfune and Ringwood 1987; Weidner and Ito 1987; Dufly and Anderson 1989; Ito and Stixrude 1992). In the mid-transition zone garnet comprises ~40 vol% of a bulk silicate earth (BSE) or ultramafic composition and up to 70 vol% of a mafic composition. Mg$_3$Al$_2$Si$_3$O$_{12}$-pyrope is the principal component in garnet formed from a BSE composition in the upper mantle, but by transition zone pressures it becomes subordinate to the Mg$_3$Si$_2$O$_{12}$-majorite component (Irfune and Ringwood 1987). Majorite forms as pyroxenes breakdown and Mg and Si substitute into the octahedrally coordinated Al site of garnet. However, at the base of the transition zone and in the lower mantle the exsolution of CaSiO$_3$ perovskite and the formation of bridgmanite drive the garnet composition to be pyrope-rich once more (Nishihara and Takahashi 2001; Saikia et al. 2008). As a consequence of the high abundance of garnet in the mantle and the significance of the pyrope component, experimental studies on the elasticity of this end-member are important for the interpretation of seismic velocities throughout the top 750 km of the mantle (Bass and Anderson 1984; Dufly and Anderson 1989; Cammarano et al. 2003; Li and Liebermann 2007).

Many earlier studies of the elastic properties of pyrope were performed at ambient temperature (Chen et al. 1999; Conrad et al. 1999; Sinogeikin and Bass 2000) or at ambient pressure and high temperatures (Sumino and Nishizawa 1978; Suzuki and Saikia 2006, 2007) and 20 GPa and 1700 K (Zou et al. 2012). However, to date no studies have extended to the pressures and tempera-