Fe\textsuperscript{2+} -Mg partitioning between garnet, magnesiowüstite, and (Mg,Fe)\textsubscript{2}SiO\textsubscript{4} phases of the transition zone

DANIEL J. FROST*

Bayerisches Geoinstitut, Universität Bayreuth, D-95447 Bayreuth, Germany

ABSTRACT

The partitioning of Fe and Mg between garnet coexisting with olivine, wadsleyite, ringwoodite and magnesiowüstite solid solutions has been measured between 9 and 19 GPa and 1400–1700 °C. In addition to studying exchange reactions involving the pyrope-almandine garnet solid solution, majoritic garnets forming in a natural peridotite bulk composition have been also examined. Metallic Fe was added to all bulk compositions to buffer the Fe\textsuperscript{3+} concentration at its lowest possible level. Partitioning data between pyrope-almandine garnet and ringwoodite were combined with data for garnet-magnesiowüstite and ringwoodite-magnesiowüstite partitioning to refine thermodynamic mixing properties for these solid solutions at 18 GPa and 1400 °C. A multiple non-linear regression employing cation exchange data between these 3 solid solutions yielded the following well-constrained values for the differences in symmetric solid-solution interaction parameters: $W_{Fe^{2+}_{Mg}}^{mw} - W_{Fe^{2+}_{Mg}}^{ring} = 8.8(2)$ kJ/mol, $W_{Fe^{2+}_{Mg}}^{mw} - W_{Fe^{2+}_{Mg}}^{gt} = 12.8(5)$ kJ/mol, $W_{Fe^{2+}_{Mg}}^{ring} - W_{Fe^{2+}_{Mg}}^{gt} = 4.0(4)$ kJ/mol.

These differences were then solved simultaneously to give, on a single site basis: $W_{Fe^{2+}_{Mg}}^{mw} = 13.2(3)$ kJ/mol, $W_{Fe^{2+}_{Mg}}^{ring} = 4.4(2)$ kJ/mol, $W_{Fe^{2+}_{Mg}}^{gt} = 0.3(3)$ kJ/mol.

In a peridotite composition, the occurrence of majorite and grossular garnet components produced a measurable influence on the Fe-Mg partitioning, however, the combined effect was relatively small because each individual component affected the partitioning in an opposite direction. These data, combined with previously determined phase relations in the Mg\textsubscript{2}SiO\textsubscript{4}-Fe\textsubscript{2}SiO\textsubscript{4} system, were used to calculate the influence of garnet Fe-Mg partitioning on the pressure intervals of divariant (Mg,Fe)\textsubscript{2}SiO\textsubscript{4} phase transformations in the transition zone. Results show that the presence of garnet reduces the pressure interval over which the (Mg\textsubscript{0.9},Fe\textsubscript{0.1})\textsubscript{2}SiO\textsubscript{4} olivine to wadsleyite transformation occurs in a peridotite composition to 0.35 GPa (10 km) in comparison to 0.5 GPa in a garnet-free system. This width, however, is still greater than the estimated width of 4 km for the 410 km discontinuity observed in some regions of the Earth as inferred from high frequency reflected and converted seismic waves. The existence of garnet in a peridotite composition in the mantle cannot, therefore, be the only explanation as to why the 410 km discontinuity is, in some regions of the Earth, apparently sharper than experimental estimates for the (Mg\textsubscript{0.9},Fe\textsubscript{0.1})\textsubscript{2}SiO\textsubscript{4} olivine to wadsleyite transformation. The wadsleyite to ringwoodite transformation is reduced to 0.8 GPa (25 km) compared to 1 GPa in the garnet-free system.

INTRODUCTION

Garnet is likely to be the second most abundant mineral throughout the transition zone and much of the upper mantle (Ringwood 1991). Over this range of stability, the composition of garnet will change significantly due to the influence of pressure on the partitioning relations between garnet and the other minerals of the mantle (Akaogi and Akimoto 1977; Irifune 1987; Irifune and Ringwood 1993; Irifune 1994). There are, not surprisingly, several reasons why it is important that we can predict the likely composition of garnet over a range of conditions. Recent studies have shown, for example, that the pressure interval of the divariant (Mg,Fe)\textsubscript{2}SiO\textsubscript{4} olivine to wadsleyite transformation will be significantly narrowed in the presence of garnet due to the difference in Fe-Mg partitioning between garnet and each (Mg,Fe)\textsubscript{2}SiO\textsubscript{4} phase (Stixrude 1997; Irifune and Isshiki 1998). The 410 km seismic discontinuity, which is believed to be caused by the olivine to wadsleyite transformation, is observed seismically to be very sharp and, in some regions of the Earth, appears to occur over a pressure interval of less than 0.2 GPa (Benz and Vidale 1993). This sharpness is apparently at odds with experimental estimates of the pressure interval of this divariant reaction, which are closer to 0.5 GPa (Katsura and Ito 1989; Fei and Bertka 1999). The presence of garnet in the mantle, which is a significant sink for Fe and Mg, could therefore explain this difference between the experimentally and seismically determined transformation intervals. An accurate knowledge of the partitioning relationships between garnet and other minerals is also required for thermobarometric calculations for the depth of origin of proposed ultra high-pressure peridotite terranes, mantle xenoliths, and inclusions in diamond (Van Roermund et al. 2001; Harte et al. 1999).

Here I report measurements of Fe and Mg partitioning be-