

PYROXENE-GARNET SOLID SOLUTION EQUILIBRIA IN THE EARTH'S MANTLE

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Pyroxene-garnet solid solution equilibria have been studied in the pressure range 41 to 200 kbar over the temperature range 850 to 1450°C for the system enstatite-pyroxene and in the pressure range 30 to 105 kbar over the temperature range 1000 to 1300°C for the system ferrosilite-almandine. Preliminary investigations have also been progressing on the system $\text{Ca}_2\text{Mg}_2\text{Si}_4\text{O}_{12}$ - $\text{Ca}_{1.5}\text{Mg}_{1.5}\text{Al}_2\text{Si}_3\text{O}_{12}$ in the pressure range 68 to 190 kbar at 1200°C. These phase equilibrium experiments were made using three types of high pressure apparatus — a tetrahedral anvil type, a cubic anvil type, and a double-staged cubic-octahedral anvil type. Pressure values in these multi-anvil apparatus were calibrated by means of several pressure fixed points. Latest data in our laboratory on the transformation pressure of high-Ba(126 kbar), Pb(142 kbar), ZnS(162 kbar), and GaAs(193 kbar) were adopted as fixed points between 100 and 200 kbar. High temperature correction was further made based on the phase boundary curves between coesite and stishovite, $P(\text{kbar}) = 80 + 0.011T(^{\circ}\text{C})$, and between pyroxene and ilmenite in ZnSiO_3 , $P(\text{kbar}) = 91 + 0.02T(^{\circ}\text{C})$, which were recently determined by means of in situ x-ray measurements.

Phase relationships in the system $\text{Mg}_4\text{Si}_4\text{O}_{12}$ - $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ at 1000°C are shown in Figure 1. The solid solubility of enstatite in pyroxene increases gradually to 140 kbar and then suddenly in the pressure range 140 to 175 kbar, resulting in formation of homogeneous garnet with composition $\text{Mg}_3(\text{Al}_{0.8}\text{Mg}_{0.6}\text{Si}_{0.6})\text{Si}_3\text{O}_{12}$. In the MgSiO_3 rich field, the three phase assemblage of $\beta\text{Mg}_2\text{SiO}_4$ (or $\gamma\text{Mg}_2\text{SiO}_4$), stishovite and a garnet solid solution is stable at pressures above 175 kbar. Although these results support qualitatively

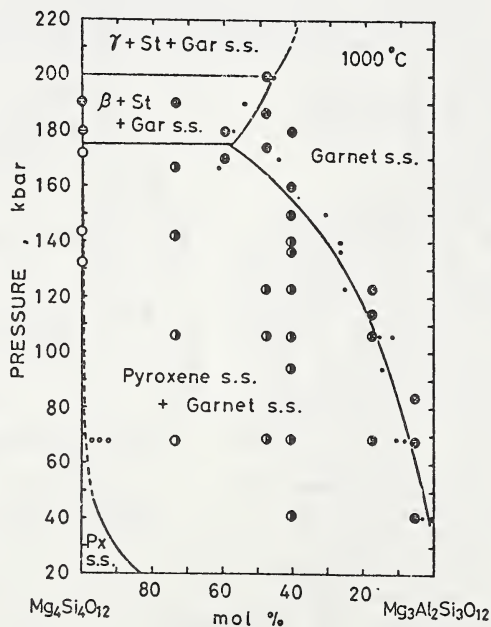


Figure 1

Ringwood's idea on the pyroxene-garnet transformation in the system $\text{Mg}_4\text{Si}_4\text{O}_{12}$ - $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$, some quantitative disagreements were found between these two investigations. He suggested

that a glass with the composition of $\text{MgSiO}_3 \cdot 10\% \text{Al}_2\text{O}_3$ (wt%), corresponding to $[\text{Mg}_4\text{Si}_4\text{O}_{12}]_{0.6} \cdot [\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}]_{0.4}$, completely crystallized to the garnet structure at pressures around 110 kbar at 1000°C.

The system ferrosilite-almandine shows the similar trend of high pressure transformations (Figure 2): maximum solubility of ferrosilite in almandine for forming a homogeneous garnet solid solution is 40 mol% at 93 kbar and 1000°C. A systematic increase in the solid solubility of diopside component in $\text{Ca}_{1.5}\text{Mg}_{1.5}\text{Al}_2\text{Si}_3\text{O}_{12}$ garnet with increasing pressure was also observed at pressures above about 100 kbar at 1200°C.

If the pyrolite mantle is assumed and further high pressure transformations of pyroxenes with 10wt% R_2O_3 ($=\text{Al}_2\text{O}_3 + \text{Cr}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) in the pyrolite mantle are approximated by those of a simple composition of $\text{MgSiO}_3 \cdot 10\% \text{Al}_2\text{O}_3$, from the present results, the following transformation scheme is suggested for the pyroxene-garnet assemblage. The pyroxene-garnet transformation is spread over more than 400 km in depth from about 120 to 540 km. At the latest range in depths between 450 and 540 km, pyroxenes transform effectively to a complex garnet solid solution. Complete disappearance of pyroxenes in the mantle takes place at about 540 km in depth. The complex garnet solid solution is expected to be stable at depths between 540 and 590 km. At deeper depths, it will decompose to a three-phase mixture of modified spinel (β phase) or spinel (γ phase), stishovite and garnet solid solutions dissolving lower amount of pyroxene component.

Zero pressure densities for the composition of $[\text{Mg}_4\text{Si}_4\text{O}_{12}]_{0.6} \cdot [\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}]_{0.4}$ at varying pressures or depths are calculated and shown in Figure 3. In the range of depths from about 450 to 540 km, high gradient of the density increase appears. It is likely that this leads to about 2 % increase in P-wave velocity at that depth range. It is concluded that the pyroxene-garnet transformation is responsible for the minor seismic discontinuity around 500 km in depth.

Since the garnets at depths below about 150 km

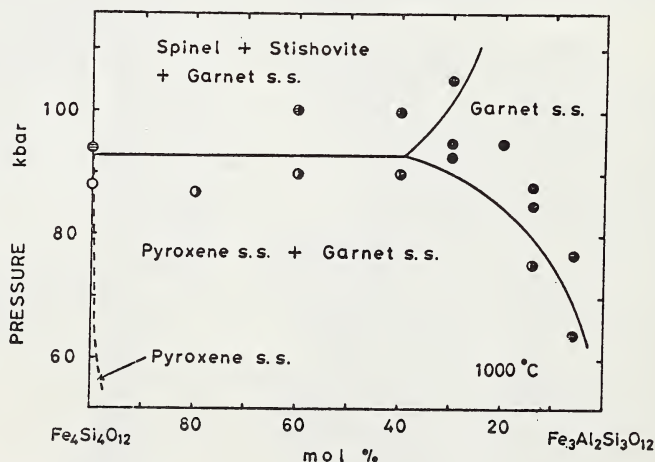


Figure 2

dissolve an appreciable amount of pyroxene component, natural finding of garnet with the atomic number of Si higher than 3 is very probable in the ultramafic inclusions in kimberlites.

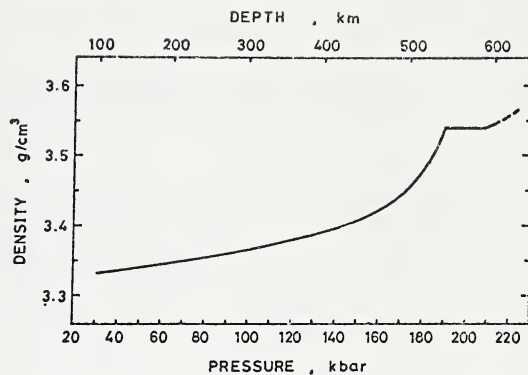


Figure 3