The near-solidus transition from garnet lherzolite to spinel lherzolite

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Mid-ocean ridge basalt (MORB) is thought to be generated mainly in the spinel lherzolite stability field. However, there is some evidence for early melting in the presence of garnet (e.g. Hirschmann and Stolper, 1996). If melting started in the garnet lherzolite stability field, simple melting models predict a thickness of the oceanic crust much greater than the average crust measured of 7 ± 1 km by seismological studies. Several possible solutions have been proposed to resolve this apparent conflict, summarised by Hirschmann and Stolper (1996).

However, in order to model the processes of mantle melting it is, of course, indispensable to have reliable data on the exact position of the transition from spinel lherzolite to garnet lherzolite.

The system CaO-MgO-Al_2O_3-SiO_2 (CMAS) is an excellent starting point because its composition represents up to 90% of the Upper Mantle's composition and because it contains all of the major chemical constituent phases such as olivine, garnet, spinel, orthopyroxene and clinopyroxene. Several studies have investigated the transition from garnet lherzolite to spinel lherzolite in CMAS at lower temperatures (O'Neill, 1981; Jenkins and Newton, 1979). However, there is little and, unfortunately, controversial information available for the high temperature part of the univariant reaction, the region where magmas are likely to be generated.

The reaction that defines the phase transition from spinel to garnet lherzolite in the simple system (MgO-Al_2O_3-SiO_2) MAS may in essence be written as follows:

$$2\,Mg_2Si_2O_6 + MgAl_2O_4 = Mg_2SiO_4 + Mg_3Al_2Si_3O_{12} \quad (1)$$

This reaction remains univariant in the system CaO-MgO-Al_2O_3-SiO_2 (CMAS) if an additional calcium-containing phase, in our case clinopyroxene, remains present to buffer the chemical potential of CaO.

There are, in principle, two ways to investigate reaction (1):

Firstly, the transition may be investigated *directly* by performing a reversal study with samples containing both reactants and products are equilibrated in divariant fields both above and below an univariant reaction.

A different approach investigates alumina isopleths of pyroxenes, that is lines of constant composition. Because of the very different slopes of the Al-isopleths (lines of constant composition) in the spinel lherzolite and garnet lherzolite stability fields, respectively, the position of the univariant reaction can be determined *indirectly* in pressure-temperature space by determining where the isopleths intersect.

In this study we investigated the transition of garnet- to spinel lherzolite near the solidus using both approaches. We have directly reversed the position of the univariant reaction in CMAS near the solidus, at temperatures from 1200°C to 1500°C and pressures from 18 to 26 kbar and we have also investigated the solubility of Al_2O_3 in pyroxenes near the solidus.

Experiments

High-pressure, high-temperature experiments were carried out in a conventional piston-cylinder apparatus using a ½ inch diameter NaCl-pyrex assembly. All experiments were performed using the 'piston-out' method.

As a check on pressure calibration, the position of the univariant reaction $Fe_2SiO_4 + SiO_2 = 2\,FeSiO_3$ was reversed, as described by Klemme and O'Neill (1997).

Temperatures were measured with $Pt_{94}Rh_6$–$Pt_{70}Rh_{30}$ thermocouples (type B) inserted axially into the assembly inside two- or four-bore high purity Al_2O_3 tubing. Because thermocouple drift due to contamination is always a potential hazard in piston-cylinder experiments at high temperatures, temperatures in some runs (particularly the higher temperature ones) were additionally monitored with a second thermocouple of $W_{75}Re_{25}$–$W_{97}Re_3$ (type C. Temperatures as measured by the two thermocouples differed only by a maximum of 10°C. All run products were analysed using electron microprobe techniques.

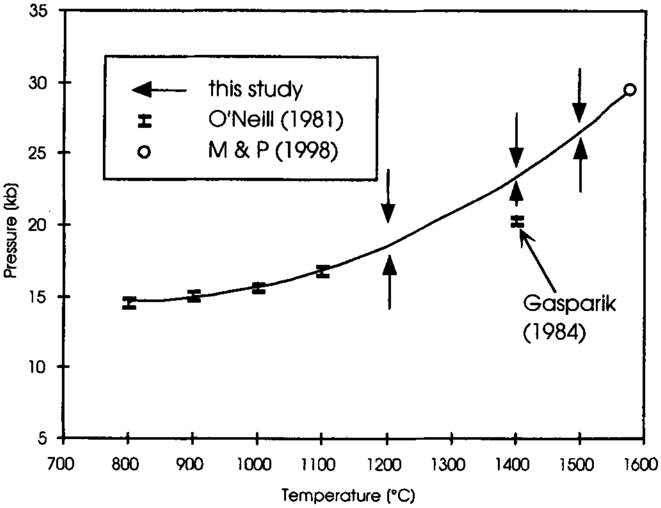

FIG. 1. The transition from spinel lherzolite to garnet lherzolite in the system CaO-MgO-Al_2O_3-SiO_2. Our data agree well with results from O'Neill (1981) and Milholland and Presnall (1998) [M&P], but disagree considerably with brackets by Gasparik (1984).

Results

Preliminary results (Fig. 1) show that the transition from garnet to spinel lherzolite occurs at higher pressures than predicted by previous studies at elevated temperatures (>1200°C), the region in P/T space relevant for mantle melting.

Studies by Jenkins and Newton (1979) and O'Neill (1981) in well reversed experiments found a strong curvature below temperatures of 1300°C, resulting in a slope of the reaction that was nearly parallel to the temperature axis.

Information on the high-temperature part of the univariant reaction, however, is much less abundant and, unfortunately, controversial. The only previous experimental reversal at temperatures higher than 1200°C for which electron microprobe analyses of pyroxenes are available is given by Gasparik (1984) which falls 3.5 kb below our curve. Recently, Milholland and Presnall (1998) reported a datum at 1575°C and 30 kbar for the transition from garnet to spinel lherzolite on the solidus, which is in good agreement with our results.

Our experimental brackets also agree well with the studies in the low-temperature regime (800°C–1200°C) (c.f. O'Neill, 1981; Jenkins and Newton, 1979) as depicted in Fig. 1. The studies in the low-temperature range from 800–1100°C agree well with each other, provided that a pressure correction is applied to O'Neill's (1981) data because of the rigid talc-pyrex assembly used.

We have constructed a comprehensive thermodynamic model for phase relations involving olivine, spinel, garnet and aluminous pyroxenes (both ortho- and clino-) in the system CMAS, which reproduces well both the position of the univariant curve and the alumina solubilities in the pyroxenes in the CMAS system. This model is now being extended to include the effects of Cr and Fe^{2+}.

References

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