

EXPERIMENTAL DETERMINATION OF GARNET-SPINEL COEXISTING LHERZOLITE FACIES AND TRACE ELEMENT DISTRIBUTION

Kenneth T. Koga *, Nobumichi Shimizu** and Timothy L. Grove***

* MIT/WHOI Joint Program, WHOI, Woods Hole, MA 02540, U.S.A.

** Woods Hole Oceanographic Institution, Woods Hole, MA 02540, U.S.A.

*** Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.

ABSTRACT

The pressure-temperature location of garnet and spinel lherzolite facies boundary is often critical for understanding mantle dynamics. We have investigated the boundary by experiments using natural starting materials. For compositions close to the model primitive mantle at constant temperature of 1360°C, garnet-in boundary is approximately 2.3 GPa while spinel-out is at approximately 2.6 GPa. The redistribution of trace elements during the garnet break down reaction (i.e. olivine[ol] + garnet[gt] = orthopyroxene[opx] + clinopyroxene[cpx] + spinel[sp]) lags behind phase equilibrium and product opx and cpx "inherit" the REE abundances from reactant garnet. Diffusion equilibration for trace elements takes several hundred thousand years for pyroxenes over distance of 500µm at 1200°C.

The pressure-temperature data for garnet-spinel transformation are inadequate particularly under near solidus conditions in natural peridotite compositions. Previous experimental studies have demonstrated that compositional effects on the location of garnet-spinel facies boundary in simple systems were considerable (e.g. Nickel, 1986; O'Neill, 1981). Addition of chrome shifts the boundary to higher pressures, but the data are not sufficient for extrapolating the results to natural compositions. For natural systems, experimental studies of the transformation boundary are limited in number (Jenkins and Newton, 1979; O'Hara et al., 1971) and their results span over a range approximately 10 kbar. Furthermore, experimental results for the transformation boundary near solidus (above 1300°C) do not exist. Our experiments were aimed at determining where garnet and spinel become stable at near solidus condition (e.g. 1360°C). In addition, the phase rule predicts a range of pressure-temperature conditions for the existence of transitional garnet-spinel lherzolite zone, because the degree of freedom is more than two for the garnet break down reaction in the natural system. This suggests that the garnet-in boundary is located toward the lower pressures than the spinel-out boundary.

We circumvent the problem, that is caused by sluggishness of reaction, by monitoring rates of the garnet break-down and growth reactions. Model parameters corresponding to chemical affinity are determined from time dependent progresses of the reaction. These parameters are used to extrapolate the condition where reaction rate is zero, that is equilibrium. The results show that at 1360°C garnet-in boundary is located at 0.3 GPa lower pressure than spinel-out boundary. Garnet and spinel can coexist in the range of pressure. It should be noted that the 0.3 GPa pressure range for the coexistence is difficult to resolve by the conventional reversal reaction method (Koga et al., 1998).

Trace elements that reside in garnet have to be redistrib-

uted during the garnet break-down reaction. Peridotite samples that have experienced the decompression often display incomplete trace element redistribution in newly formed minerals. Trace element measurements on experimental charges demonstrate that product opx and cpx "inherit" the trace element abundance from the reactant garnet, and there are no recognizable differences in abundance of trace element between opx and cpx. Thus, while major element abundances in pyroxenes are in equilibrium as demonstrated by experimentally calibrated geothermobarometers, trace element redistribution is incomplete. This may be caused by the differences in diffusivities of major and trace elements.

The disequilibrium trace element distribution similar to experimental results could be expected in rocks under went rapid decompression. Indeed, The trace element distribution among fine grained rims around garnet consisting opx, cpx, and spinel in peridotite xenoliths from Lashaine, Tanzania closely resembles experimental results. Time scales for equilibration of pyroxenes can be modeled by diffusion. A model involving a spherical grain with a constant composition boundary, and a model with adjacent finite length slabs of opx and cpx, are compared under various diffusivities and boundary conditions in cooling histories. The results show persistence of disequilibrium for 7-800k years at high temperature (1200°C), and fractionated zoning of rare earth elements due to $D(\text{Yb}) > D(\text{La})$.

Starting materials are mineral separates from garnet lherzolite from Pali Aike, Chile for garnet break down and spinel lherzolite from Kilbourne Hole, USA for garnet production reaction. Experiments are conducted at the conditions at 1360°C and from 1.8 to 3.0 GPa, with the run duration spanning from 2 to 200 hours. The run conditions were achieved by 2.54 cm diameter piston-cylinder type apparatus, with BaCO₃ as pressure transmitting medium. Pressure calibrations were done by the CaTs break-down reaction (Hays, 1967) and An-Sp lherzolite transformation for CMAS system at subsolidus and above solidus conditions (Kushiro and Yoder, 1966). Volume fractions of product phases are measured from the digitally captured back-scattered electron images with the combination of x-ray images. Major element compositions are measured by electron probe. Trace elements abundances are measured by ion probe.

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