EXPERIMENTAL STUDY OF AMPHIBOLE AND PHLOGOPITE STABILITY IN METASOMATIZED PERIDOTITE UNDER WATER-SATURATED AND WATER-UNDERSATURATED CONDITIONS

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The specific composition of kimberlitic and alkali-basaltic melts enriched in incompatible elements has been interpreted by many authors as a result of metasomatic alteration of the source peridotite. Evidence for metasomatism in the mantle also arises from peridotite xenoliths brought up by these magmas. In such xenoliths, amphibole and phlogopite are the predominant products of metasomatic reactions. These minerals contain large proportions of incompatible elements such as K, Rb, Ba, Cs etc. relative to the unhydrous phases of the peridotite. Their stability at high pressures plays an important role in the formation of highly enriched mafic melts.

High pressure experiments were carried out on a natural peridotite composition (NHD peridotite) which was derived from a suite of spinel harzburgite and lherzolite xenoliths from the Northern Hessian Depression (NW Germany) (Wedepohl, 1985). The normative mineralogy of NHD peridotite is 78 % olivine, 18 % orthopyroxene, 7 % clinopyroxene, 1 % Cr-spinel and 1.5 % phlogopite. From this composition, 60 % olivine was subtracted to avoid the dominance of olivine in the charge products. The starting composition was made from synthetic oxides. Experiments were run in a piston cylinder apparatus using Ag-Pd capsules. The run products were examined by optical methods and all phases except glass and spinel were analyzed by electron microprobe whenever their grain size was large enough ( $\gtrsim 3$  µm).

For experiments at water-saturated conditions, 1 % water was added by a microsyringe to approximately 15 mg of the starting mix (NHD peridotite minus 60 % olivine), which is equivalent to 0.4 % water in the original NHD peridotite (no olivine subtracted). These experiments yielded subsolidus assemblages of olivine, orthopyroxene, clinopyroxene, amphibole, phlo-gopite, spinel (and garnet). The solidus was easily determined by the appearance of glass and textural changes of the charge. It resembles the solidus curves for pyrolite (Green, 1973) and for St. Pauls peridotite (Millhollen et al., 1974) at water-saturated conditions. Amphibole and phlogopite are present above the solidus at 15 and 25 kb. Phlogopite was observed above the solidus at 30 kb, 1030° C. These phases coexist with olivine, orthopyroxene, clinopyroxene, spinel (garnet) and liquid. The compositions of olivine, orthopyroxene, clinopyroxene, amphibole, phlogopite (and garnet) are very similar below and above the solidus at 15 and 25 kb. The K/Na ratio of the amphiboles is lower than that of the starting material and is probably buffered by the occurrence of phlogopite. The composition of the liquids could not be determined because the glass was modified by quench crystallization of olivine and pyroxenes. Unlike com-parable experiments on pyrolite (Green, 1976) there is no significant increase in 100 Mg/Mg+Fe (Mg-number) of the residual phases in NHD peridotite when the solidus is crossed (15 and 25 kb). The amount of melt formed near the solidus, thus, cannot exceed a few percent.

For the experiments at water-undersaturated conditions the starting material (NHD peridotite minus 60 % olivine) was presaturated with water (2 %) in large capacity runs at 15 kb,  $925^{\circ}$  C. The excess water was driven out after the experiments at  $450^{\circ}$  C. The amount of water remaining in the charge was 0.4 % (equivalent to 0.15 % water in the original NHD peridotite). The large capacity run products consist of 30 % olivine, 30 % orthopyroxene, 21 % amphibole, 3 % phlogopite and 2 % Cr-spinel. All water is exclusively locked in amphibole and phlogopite.

The solidus of NHD-peridotite at water-undersaturated conditions coincides with the disappearance of amphibole. Within the experimental brackets no amphibole was observed above the solidus. The shape of the amphibole breakdown curve resembles that in pyrolite under water-undersaturated conditions (Green, 1973) but it is confined to approximately 2 kb lower pressures. This is probably due to the lower concentrations of alkalis, Ti and Al in NHD peridotite. Phlogopite, however, persists to temperatures of up to  $150^{\circ}$  C above the solidus (28 kb). The linear shape of the upper stability of phlogopite in NHD-peridotite is similar to that suggested by Wendlandt and Eggler (1980) for a natural peridotite containing 10 % additional phlogopite. Phlogopite is an abundant quench phase at 25 kb,  $1200^{\circ}$  C and at 28 kb,  $1250^{\circ}$  C. It occurs as relatively large platelets which cannot be distinguished easily from primary phlogopites at lower temperatures. A clear distinction between primary and quench phlogopite can only be achieved by microprobe analyses. Quenched phlogopites are much higher in Ti and Fe and lower in Cr contents compared to primary phlogopite. The back bending of the amphibole stability curve between 25 and 28 kb leads to a wide P,T field where a liquid (liq 1) coexists with olivine, orthopyroxene, clinopyroxene, spinel (and garnet) and phlogopite. At 25 and 28 kb an increase in Mg-number of olivine, opx, cpx, garnet and phlogopite is observed with increasing temperatures across the solidus. This can be explained by the formation of a melt (Mg-number 70 to 76) by the breakdown of amphibole. At 28 kb the compositions of the residual phases are fairly constant in the phlogo-pite-present melting interval over a range of more than 100° C. A further increase in Mg-number of residual olivine and orthopyroxene is observed in the phlogopite-absent melting region. At 25 kb, 1200° C and 28 kb, 1250° C the residual clinopyroxenes have lower Mg-numbers and lower Ca/Al-ratios when compared to the phlogopite-present melting region. The compositions of the liquids (glass) in both regions could not be determined directly by microprobe, but it is highly probable that liquids in the phlogopite-present melting interval (liq 1) have a different composition (e.g. lower K/Na-ratios) from those in the phlogopite-absent melting range (liq 2).



Fig. 1: Stability of amphibole and phlogopite in NHD peridotite under water-saturated and water-undersaturated conditions. Coexisting phases are olivine, orthopyroxene, clinopyroxene, spinel (and garnet).

In an attempt to characterize the nature of these liquids, "sandwich" experiments were carried out at 28 kb, 1250° C and 28 kb, 1195° C. A layer of basanite glass (NHD basanite) containing 4 % water was embedded between two layers of NHD peridotite minus 60 % olivine (presaturated with water). The residual phases in the peridotite layers were directly analyzed by electron microprobe. The glass in the basanite layer was quench modified as in the non-sandwich experiments. Small amounts of glass are also observed within the upper and the lower peridotite layers. Microprobe analyses from this glass gave significant amounts of P2O5. Because there was no P added to the peridotite starting mix, this obser-vation is taken as evidence for a mixing between the melt formed within the peridotite layers and the embedded basanitic melt. Areas of 20 to 50 µm were analyzed in the basanite layer with a scanning electron beam to include quenched phases (mainly clinopyroxene) and to avoid vaporization of the alkalies in the analysis. Each set of area scan analyses represents a compositional spectrum of the basanite layer with a large range of Mg-numbers depending on the amount of quenched phases included in the scan analyses. Within a set of such analyses the Si, Ti, Al, Fe, Mg, Ca and P are correlated with the Mg-number reflecting the proportions of guenched crystals in each area scan. From Mg-number versus oxide plots the composition of the liquid in equilibrium with the peridotite is estimated using the olivine/liquid Mg-Fe KD of Takahashi and Kushiro (1983) to choose an appropriate Mg-number for the basanite liquid. A sandwich experiment at 28 kb,  $1250^{\circ}$  C had residual olivine, orthopyroxene, clinopyroxene, garnet and minor spinel in the peridotite layers. At 28 kb, 1195° C phlogopite was stable as an additional residual phase beside these phases. These are the same residual phase assemblages as in experiments at the same conditions where no basanite was added. The composition of the residual phases has changed very little when compared with those in the non-sandwich experiments. Therefore, the composition of the liquids in the non-sandwich experiments cannot be very different from that of the basanite used in the sandwiched layer. The composition of the liquid in the 28 kb, 1195° C experiment (residual phlogopite) as calculated from Mg-number versus oxide plots reveals a greater similarity to that of NHD basanite than the liquid in the 28 kb,  $1250^{\circ}$  C experiment where all phlogopite has entered the melt. The glass in the latter experiment has a much higher K/Na ratio, reflecting the total consumption of phlogopite. The K/Na ratio of the liquid in the 28 kb, 1195° C sandwich experiment has the same K/Na ratio as NHD basanite and the other alkali basaltic species from the northern Hessian Depression, indicating that the respective melts have formed in the P,T field where phlogopite is a residual phase.

This experimental approach permits the testing of models with low degrees of partial melting of peridotite where direct analyses of the quenched liquid present in the experimental charge are not feasible.

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