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Phase relations of an aphanitic kimberlite from the Wesselton mine, Kimberley, South Africa have been determined at 10-40 K bar and 1000-1525°C. This kimberlite is fine-grained with low macrocrystic olivine content which distinguishes it from other macrocrystic Type I kimberlites from the same locality. From this study, crystallization paths in the aphanitic kimberlite at depth can be compared with those inferred from its petrography and some suggestions made as to the source material for this unusual kimberlite.

PETROGRAPHY AND GEOCHEMISTRY

The petrography and geochemistry of aphanitic and macrocrystic Wesselton kimberlites (Shee 1984) indicate that the aphanitic varieties can be distinguished by olivine microphenocrysts in a groundmass of calcite, monticellite, ilmenite, spinel, perovskite, apatite, serpentine and rare phlogopite. Xenocrysts of olivine and phlogopite and xenoliths only occur in trace amounts. Whole rock analyses indicate Mg/Mg + Fe, K/K + Na and Ca/Ca + Mg ratios range from 0.80-0.86, 0.13-0.81 and 0.24-0.29 respectively. Olivine microphenocrysts have Mg/Mg + Fe of 0.83-0.95. Groundmass monticellites have Mg/Mg + Fe of 0.92-0.94, spinels have chromite-rich cores and titanomagnetite-rich rims.

EXPERIMENTAL METHODS

Experiments were done in a 1.27 cm piston-cylinder apparatus in Fe-soaked Pt, Pt and Ag₅₀Pd₅₀ capsules. Pressures and temperatures are considered accurate to ±0.5 K bar and ± 5°C respectively. Runs were buffered at f_{O_2} s equivalent to $\Delta QFM \ll NNO$ buffers by the graphite furnaces used (Brey and Green 1975). Experiments were done with no added volatiles ($X_{CO_2} = CO_2 / (CO_2 + H_2O) \text{ mol.} = 0.24$) and with CO_2 added as $Ag_2C_2O_4$ at $X_{CO_2} = 0.52$. Identification of products was made optically, by X-ray diffraction and by electron microprobe.

RESULTS

Results of experiments at $X_{CO_2} = 0.24$ (Fig. 1a) show that olivine, clinopyroxene, spinel, monticellite, perovskite and calcite are primary crystalline phases. Quench and primary phases were distinguished by their morphology and/or composition. Olivine is on the liquidus up to 40 K bar with spinel and clinopyroxene as additional phases at 5-65°C and 60-135°C below the liquidus respectively. At slightly greater than 40 K bar the "spinel in" curve intersects the liquidus (Fig. 1a) resulting in olivine + spinel as the liquidus assemblage. Calcite is the primary carbonate about 70°C subliquidus at 35 K bar to >300°C at 10 K bar. Below about 13 K bar, 1000-1250°C monticellite occurs with olivine + spinel + perovskite + calcite. Clinopyroxene is absent in all runs with monticellite, suggesting some type of reaction relationship. Distinction between primary and quench perovskite is difficult but appears to lie at temperatures below "calcite in" curve (Fig. 1a).

The effect of increasing CO_2 to $X_{CO_2} = 0.52$ is shown in Fig. 1b. In these runs identification is more difficult due to the abundance of fine-grained quench products. The liquidus is at a slightly higher temperature and the olivine + spinel + calcite near liquidus assemblage gives way to clinopyroxene + olivine + spinel + calcite at slightly greater than 35 K bar. The incoming of clinopyroxene occurs near the liquidus at 35 K bar decreasing to >100°C below the liquidus at 20 K bar. In contrast to the lower X_{CO_2} experiments (Fig. 1a), calcite occurs in all runs presumably due to the higher a_{CO_2} . As clinopyroxene increases with decreasing temperature, dolomite crystallizes as a second carbonate phase possibly caused by the depletion of Ca in residual liquids. Below the "dolomite in" curve, olivine is rare or absent. The nature of the products of these runs does not permit unequivocal identi-

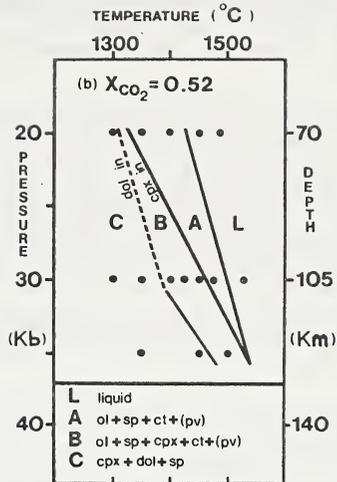
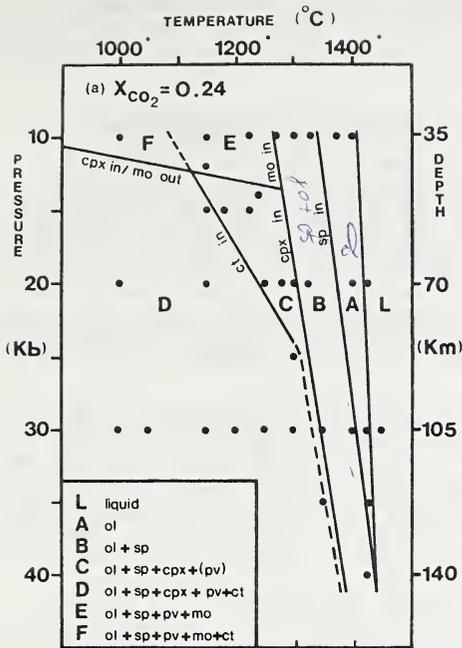


Fig. 1. Experimental results (a) $X_{CO_2} = 0.24$. No added volatile (b) $X_{CO_2} = 0.52$. Abbreviations -- ol-olivine, sp-spinel, cpx-clinopyroxene, pv-perovskite, mo-monticellite, ct-calcite, dol-dolomite. Brackets indicate phase may or may not be present.

fication of either of these carbonates as primary.

Analyses of olivines show $Mg/Mg + Fe$ of 0.90-0.98. These ratios do not differ appreciably between runs done with Fe-soaked and non Fe-soaked Pt capsules suggesting that Fe loss to the Pt was not a major problem. Clinopyroxene, although difficult to analyse due to its fine grain size, appears to be fassaite with high CaO and Al[IV]. Monticellite has $Mg/Mg + Fe$ ranging from 0.82-0.94. Perovskite analyses generally have low totals, possibly due to the presence of high Nb and REE contents (c.f. Shee, 1984; Mitchell, 1984). Although most spinel analyses are semiquantitative due to their fine-grain size, they appear to be aluminous magnesioferrite ($Mg/Mg + Fe = 0.32-0.50$) and rare aluminous magnesiochromite ($Mg/Mg + Fe = 0.54-0.58$).

DISCUSSION

These experiments can be used to indicate the possible polybaric crystallization path of the aphanitic kimberlite, to compare this path with that inferred from its petrography, to compare the mineral chemistry of the experimental and natural products, and to draw some implications as to the source material of this magma. Mineralogically, the basic differences between the experiments and the rock are the occurrence of clinopyroxene exclusively in the experiments, and ilmenite and phlogopite occurring exclusively in the rock.

The assemblage of olivine and olivine + spinel close to the liquidus between 10-40 K bar in low X_{CO_2} runs (Fig. 1a) is in accordance with their occurrence as early-formed microphenocrysts in the rock. The conditions under which the kimberlite began its rapid ascent are constrained by the results at low X_{CO_2} (Fig. 1a). The moderate temperature gap between the "spinel in" and "clinopyroxene in" curves; the antipathy between clinopyroxene and monticellite-bearing assemblages, with the latter restricted to the lower P-T range of the experiments, and the absence of clinopyroxene in the rock suggest that ascent may have begun at $>1400^{\circ}C$ at >140 km. At depths of about 35 km and $<1250^{\circ}C$ quasi-isobaric crystallization may have begun with clinopyroxene reacting out to form monticellite. At this stage, the kimberlite "took off" aided by the now enriched volatile residual liquid.

The petrography does not indicate the reaction producing monticellite which occurs in the groundmass with spinel and olivine. There is little evidence of spinel being resorbed as implied by a reaction such as $clinopyroxene + spinel + L^1 \rightarrow olivine + monticellite + L^{11}$. Lack of close association of olivine and monticellite in the

rock suggests a reaction $\text{clinopyroxene} + \text{L}^1 \rightarrow \text{monticellite} + \text{L}^{11}$. This seems unlikely as the liquid compositions would be improbably different. Based on the topology of Fig. 1a, the most feasible reaction is $\text{clinopyroxene} + \text{L} \rightarrow \text{monticellite} + \text{olivine}$.

Liquidus to near liquidus carbonates occur as calcite in low X_{CO_2} and as calcite + dolomite in high X_{CO_2} runs (Fig. 1). The presence of carbonates is well established in high pressure experiments on comparable compositions (Eggler and Wendlandt, 1979; Wyllie, 1980). The apparent contradiction between the presence of calcite as a late-stage groundmass mineral associated with serpentine in the rock and its high pressure stability may be resolved if the aphanitic kimberlite consolidated at $>10000^\circ\text{C}$; temperatures comparable to those suggested for other kimberlites (McMahon et al. 1979).

The presence of minor groundmass phlogopite and its absence in the experiments is likely due to our inability to detect this mineral near the solidus in such a low $K_2\text{O}$ composition.

Variations in the mineral chemistry in the rock and in the experiments may be due to the unrealistically high f_{O_2} in the experiments which is similar to that used for peridotite compositions (Olafsson and Eggler 1983) but slightly higher than that suggested for the Benfontein Kimberlite (McMahon et al. 1979). The Mg/Mg + Fe ratios for olivines in the experiments exceed those in the rock. Assuming appreciable Fe-loss to the Pt-capsules does not occur, then the high f_{O_2} might result in a shift in the equilibrium of $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ causing low Fe olivines. Similarly the Cr-poor, Al-rich spinels in the experiments might result from high f_{O_2} stabilizing Fe^{3+} , thus reducing Cr in the octahedral site in spinels. The characteristic spinel chemistry in kimberlites is formed under polybaric f_{O_2} conditions, not duplicated in the experiments.

The source material for the aphanitic kimberlite is difficult to determine based only on this study. However, by comparison with other experimental studies and from the chemistry of the aphanitic and macrocrystic varieties, some generalizations can be made. The greater degree of SiO_2 - undersaturation and higher normative spinel in the aphanitic relative to the macrocrystic kimberlite at Wesselton, and to the composition used in Eggler and Wendlandt's (1979) experiments makes derivation of the aphanitic from the macrocrystic, or any more SiO_2 -enriched kimberlite improbable. The absence of orthopyroxene under either X_{CO_2} conditions and the relatively low pressure at which olivine is no longer a liquidus phase under the higher X_{CO_2} conditions suggests that the aphanitic Wesselton kimberlite was not derived from a carbonated lherzolite source. Whether such high X_{CO_2} experiments are justified depends on whether the aphanitic kimberlite represents a "degassed" magma.

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