

KIMBERLITE MAGMAS FROM THE SYSTEM PERIDOTITE-H<sub>2</sub>O-CO<sub>2</sub>

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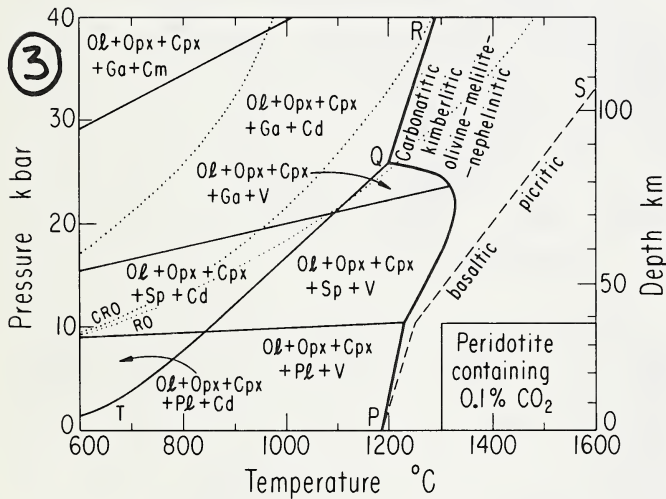
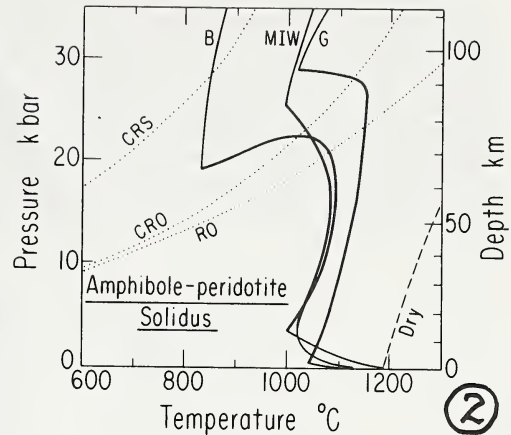
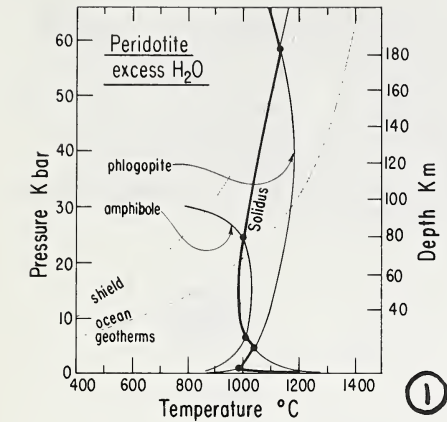
Kimberlite magmas are generated by a small degree of partial melting of mantle peridotite containing H<sub>2</sub>O and CO<sub>2</sub>, normally at depths greater than about 100 km. The presence of CO<sub>2</sub> is crucial for the development of melts sufficiently low in SiO<sub>2</sub>. Phlogopite is an obvious candidate for the source of K<sub>2</sub>O. Available experimental data from the systems peridotite-H<sub>2</sub>O-CO<sub>2</sub>, CaO-MgO-SiO<sub>2</sub>-H<sub>2</sub>O-CO<sub>2</sub>, and pyrope-magnesite can be combined to construct phase diagrams for peridotite containing H<sub>2</sub>O and CO<sub>2</sub>. Direct experimental measurement of many parts and features of these phase diagrams would be difficult, perhaps impossible. Uncertainties in results and interpretations up to 30 or 35 kbar have been discussed extensively. Results at higher pressures, for the specific problem of kimberlite genesis, are virtually non-existent.

Wyllie (1977) extrapolated available experimental data from 30 to 60 kbar in order to outline the relationships among carbonate (calcic dolomite or magnesite), phlogopite, and amphibole on the solidus surface of peridotite-H<sub>2</sub>O-CO<sub>2</sub>. Ellis and Wyllie (this volume) calculated to 100 kbar the positions of specific reactions involving carbonates and hydrous minerals in the system MgO-SiO<sub>2</sub>-H<sub>2</sub>O-CO<sub>2</sub>. The detailed phase relationships in this model system revealed intricacies in the peridotite-H<sub>2</sub>O-CO<sub>2</sub> system that will be drafted into diagrams by the time of the Conference.

Initial melting of mantle peridotite may involve (1) vapor-absent or (2) vapor-present assemblages. If we consider H<sub>2</sub>O and CO<sub>2</sub> as the only volatile components present in significant amounts, the minerals amphibole, phlogopite, and carbonate are the most likely crystalline hosts. There are three possible subsolidus vapor-absent assemblages: (a) H<sub>2</sub>O in hydrous minerals, (b) CO<sub>2</sub> in carbonate, and (c) H<sub>2</sub>O and CO<sub>2</sub> in hydrous minerals and carbonate. There are six possible subsolidus vapor-present assemblages: (a) all H<sub>2</sub>O+CO<sub>2</sub> in vapor phase, (b) H<sub>2</sub>O in hydrous minerals with excess in vapor phase, (c) H<sub>2</sub>O distributed between hydrous minerals and H<sub>2</sub>O-CO<sub>2</sub> vapor phase, (d) CO<sub>2</sub> in carbonate with excess in vapor phase, (e) CO<sub>2</sub> distributed between carbonate and H<sub>2</sub>O-CO<sub>2</sub> vapor phase, (f) H<sub>2</sub>O and CO<sub>2</sub> distributed between hydrous minerals, carbonate, and H<sub>2</sub>O-CO<sub>2</sub> vapor phase. All nine examples can be examined in the system peridotite-H<sub>2</sub>O-CO<sub>2</sub> for various pressures, temperatures, and H<sub>2</sub>O/CO<sub>2</sub>.

Fig. 1 shows the effect of excess H<sub>2</sub>O on the peridotite solidus, the maximum stability ranges of amphibole and phlogopite with peridotite and excess H<sub>2</sub>O, and the effect of phlogopite melting in lowering the peridotite solidus at pressures below 5 kbar and above about 60 kbar. Fig. 2 shows three experimentally-based versions of the solidus for different peridotites with a trace of H<sub>2</sub>O. The heavy lines show the solidus where vapor-absent amphibole-peridotite begins to melt. Fig. 3 shows the effect of a trace of CO<sub>2</sub> on peridotite. This exists as vapor at pressures below the reaction TQ, and as carbonate above TQ. CO<sub>2</sub> solubility in the near-solidus liquid increases from 1-4% to almost 40% between 20-26 kbar as the solidus drops through more than 100°C. Dolomite and peridotite melt together along QR, producing low-SiO<sub>2</sub>, high-K<sub>2</sub>O, carbonatitic liquids.

Fig. 4 shows the effect of H<sub>2</sub>O on the system peridotite-CO<sub>2</sub>. With



excess volatiles, the solidus of Fig. 3 becomes a divariant surface, PQUM. This surface is intersected by the divariant surface for the carbonation reaction QT, along the univariant line QN. Unless there is enough  $\text{CO}_2$  present to carbonate all of the clinopyroxene (unlikely in the mantle), conditions in the area QNU for melting of carbonated peridotite are not reached. Partially carbonated peridotite begins to melt along the line QN, with the vapor phase compositions buffered as shown by the contours.

Fig. 5A shows an early version of Fig. 4, with buffer lines added for the estimated maximum ranges of existence of carbonate, amphibole and phlogopite on the solidus surface. Using curve G from Fig. 2, amphibole and carbonate may just overlap on the solidus surface. Using the solidus B from Fig. 2, the solidus surface expands and the intersections change again.

Additional analysis of Fig. 5 shows that there is a univariant curve for the coexistence of carbonate and phlogopite, extending from A on the solidus surface, just below the carbonate buffer line in both temperature (Fig. 5A) and pressure (Fig. 5B). This passes below the peridotite- $\text{H}_2\text{O}$  solidus near point B (Fig. 5A, compare Fig. 1). Phlogopite and carbonate can jointly dominate near-solidus melts from depths of 80 km to about 230 km, with vapor phase buffered to very high  $\text{H}_2\text{O}/\text{CO}_2$ . High  $\text{H}_2\text{O}/\text{CO}_2$  in vapor lowers the solidus compared to that for vapor-absent carbonate-phlogopite-

peridotite, but coexistence of the first liquid with carbonate ensures generation of  $\text{CO}_2$ -rich,  $\text{SiO}_2$ -poor melt, and phlogopite ensures high  $\text{K}_2\text{O}$  in the very small amount of liquid first produced. The temperature maxima on the solidus contours (absent on Fig. 5A, see Fig. 4), now known to be much more accentuated than illustrated, show that magma rising through about 85-70 km from greater depths must evolve  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .

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