

HIGH PRESSURE MELTING EXPERIMENTS ON GROUP II KIMBERLITE UP TO 8 GPa: IMPLICATIONS FOR MANTLE METASOMATISM

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Isotopic and chemical characteristics of the group II kimberlite indicate that its mantle source region has been enriched in K, Rb, LREE and other incompatible elements. It is commonly accepted that the enrichment has been associated with the migration of mantle fluids broadly similar to kimberlite compositions, but the nature of fluids and enrichment mechanism are largely unknown. In this paper, we report phase relationships of group II kimberlite compositions up to 8 GPa and evaluate chemical characteristics of liquids in equilibrium with lithosphere mineral assemblages.

A series of high pressure experiments were carried out up to 8 GPa using group II aphanitic and macrocrystic kimberlites from Makganyene Mine, South Africa. A multianvil high pressure apparatus at Tohoku University and a piston-cylinder apparatus at Yokohama National University were used for the experiments above 4 GPa and below 3 GPa respectively. All experiments were carried out with a sealed Pt sample capsule, a Pt/PtRh13 thermocouple, and a graphite heater. The experiments above 4 GPa were done with a pyrophyllite octahedron of 18 mm edge length, and WC cubes with 12 mm truncation. Compositions of Ca-rich and Ca-poor pyroxenes in the run-products on the enstatite-diopside join at various temperatures and 8 GPa indicate a temperature variation within the sample capsule of 100 °C/mm for the runs with a straight graphite heater and 50 °C/mm for the runs with a stepped graphite heater. A majority of experiments above 4 GPa were made with a stepped graphite heater. Temperatures of phase boundaries in polished sections of the run-products were determined based on the estimated temperature gradient within the sample capsule. Kimberlite compositions used have an ultrapotassic affinity (0.76 and 0.93 K/(K+Na)) and contain 1.9-3.4 wt.% H₂O and 4.4-6.7 wt.% CO₂ (XCO₂ = 0.35-0.59) (Table 1). The macrocrystic kimberlite contains higher MgO (30.4 wt.%, #Mg=0.87) than the aphanitic kimberlite (18.4 wt.% MgO, #Mg=0.80).

The liquidus temperature of the aphanitic kimberlite composition is about 1470 °C at 6 GPa and about 1520°C at 8 GPa (Fig. 1), and that for the macroscopic kimberlite composition is about 1500 °C at 6 GPa and 1550 °C at 8 GPa (Fig. 2). They are slightly lower than that determined for the Wesselton kimberlite composition by Edgar et al. (1993). The liquidus temperatures are considerable higher (200-300°C) than H₂O-CO₂ solidus of model mantle peridotite by Canil and Scarfe (1990) and that estimated by the extrapolating the data of Wyllie (1989).

Suprasolidus phase assemblage of the aphanitic kimberlite at 1400°C varies with elevating pressure as; Phl+Liq → Phl+Cpx+Liq → Phl+Cpx+Opx+Liq → Cpx+Gt+Liq. The data indicate that phlogopite is a liquidus phase below 2 GPa and

clinopyroxene at 2-3 GPa. In the run-products above 4 GPa, a relatively wide range of temperature variation within the sample capsule hampered the precise determination of liquidus phase. The data, however, suggest that clinopyroxene + orthopyroxene + phlogopite are near-liquidus or liquidus phases at 4 GPa, clinopyroxene + orthopyroxene + garnet at 6 GPa and garnet + clinopyroxene at 8 GPa (Fig. 1). Phlogopite breakdowns between 1300-1400°C and 6-7 GPa by the reaction $\text{Phl} + \text{Cpx} = \text{Gt} + \text{Liq}$. Neither stable K-bearing, hydrate-, nor carbonate-crystalline phases were observed in the run-products above 7 GPa. The phase relationships for macrocrystic kimberlite composition are similar to those for the aphanitic kimberlite composition, except for the relatively large olivine-stability field. Olivine is a stable liquidus or near-liquidus phase even at 8 GPa. It coexists with phlogopite and clinopyroxene below 4 GPa and with clinopyroxene, orthopyroxene and garnet above 6 GPa at 1400°C. Phlogopite is not a stable phase above 6-7 GPa at 1300-1400°C.

The liquid portions of the run-products were entirely composed of fine-grained dendritic quench-crystal aggregates. The quench-crystals were olivine, pyroxene, phlogopite, garnet, and/or carbonate with non-stoichiometric and unusual compositions showing a feathery texture, features readily distinguished from euhedral primary phases. The primary orthopyroxene and clinopyroxene are comparable in composition to those of the low Cr-megacryst suite incorporated in kimberlites (Mitchell, 1986). The primary phlogopite exhibits systematic decrease of its TiO_2 content with increasing pressure, which suggest that the primary phlogopite reached equilibrium. The primary garnet at higher pressure tends to contain higher Si/Al, suggesting a presence of the majorite component.

The liquid compositions were determined by electron microprobe analyses on the quench-crystal aggregates using a defocused beam. Liquid in the run-products shows a systematic variation with temperature. At 7 GPa, it shifts toward SiO_2 - and MgO-poor, and K_2O -, Na_2O -, P_2O_5 - and TiO_2 -rich compositions as crystallization proceeds. The total oxide of microprobe analysis systematically decreases with decreasing temperature. As P_2O_5 exhibits a systematic shift with temperature and no P_2O_5 -bearing crystalline phase exists in the run-products, we can evaluate a proportion of liquid based on a P_2O_5 content of liquid and calculate volatile-contents in the liquid at various temperatures. The result indicates that the liquid compositions at 1300-1400 °C and 8 GPa are characterized by low SiO_2 (23- 27 wt. %), high K_2O (7-11 wt.%), and high volatile components (11-20 wt.% CO_2 and 3-6 wt. % H_2O). These chemical characteristics of the liquids are broadly comparable with those obtained from fluid inclusions in cubic diamonds (Navon et al., 1988) (Table 1).

The present experimental results indicate that; (1) Phlogopite is a stable K-bearing phase below about 6.5 GPa. The group II kimberlite magma can be generated by partial melting of phlogopite-bearing Iherzolite below 6.5 GPa. (2) Depending on MgO content in the magma, the group II kimberlite magma can be equilibrated with eclogitic or garnet Iherzolitic mantle above about 6.5 GPa where phlogopite is no longer stable. (3) Liquids extremely enriched in K_2O , H_2O and CO_2 and depleted in SiO_2 are stable in the subcratonic asthenosphere. Upward migration of these enriched asthenospheric liquids might result in phlogopite formation and mantle metasomatism at the asthenosphere-lithosphere boundary (about 6.5 GPa).

Table 1. Compositions of the starting materials and melts (normalized to 100 %) in the run-products of the aphanitic kimberlite at 8 GPa, in comparison to composition of diamond micro "fluid" inclusion (Navon et al. 1988)

	Aphanitic kimberlite	Macrocrystic kimberlite	melt 1350°C	melt 1300°C	Inclusion inDiamond
SiO ₂	40.9	39.1	37.1	26.6	25.4
TiO ₂	1.00	1.02	0.9	1.1	1.5
Al ₂ O ₃	5.23	3.05	3.4	4.8	3.8
FeOT	8.43	8.38	8.4	2.4	3.1
MgO	18.4	30.2	17.0	18.9	1.7
CaO	9.37	6.18	9.2	8.0	6.6
Na ₂ O	1.22	0.17	1.7	1.7	1.8
K ₂ O	5.92	3.55	6.3	10.6	14.6
P ₂ O ₅	1.09	0.79	1.7	2.8	2.0
CO ₂	6.70	4.37	10.6	17.1	11.2
H ₂ O	1.94	3.31	3.1	4.7	27.2

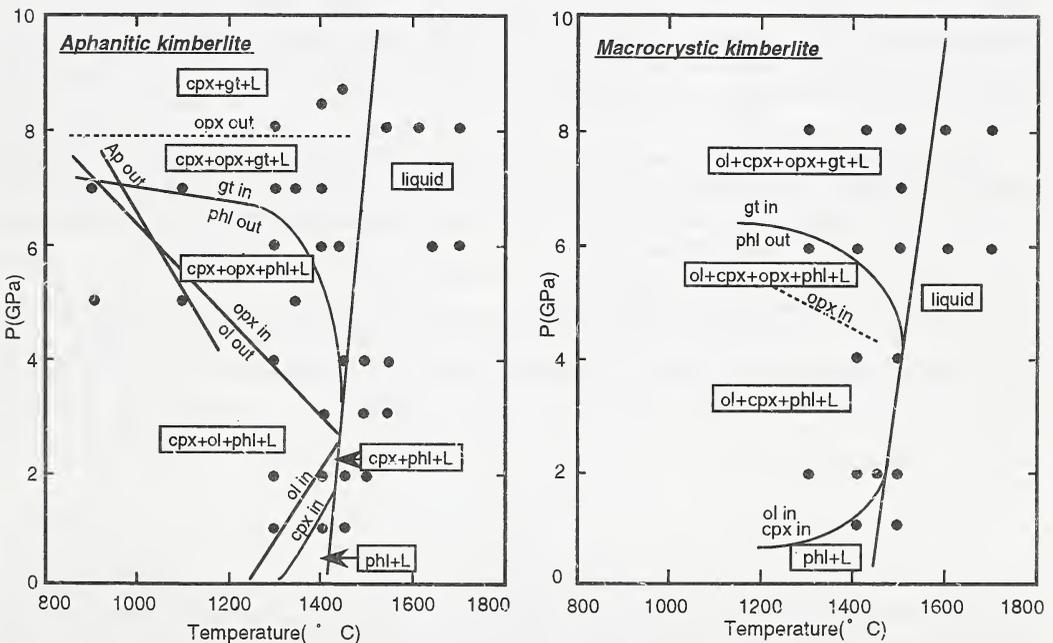


Fig. 1. P-T diagram for the aphanitic kimberlite composition (left) and for the macrocrystic kimberlite composition (right).