Melting experiments of kimberlite compositions up to 9 GPa: Determination of melt compositions using aggregates of diamond grains

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Introduction

Navon et al. (1988) and Schrauder and Navon (1994) reported mantle derived fluid compositions from diamond inclusions. Compositions of mantle fluids are characterized by high abundance of H_2O, CO_2, K_2O and LREE and depletion of MgO, those are broadly similar to group II kimberlite and lamproite compositions. These mantle fluids might play important roles in generation of kimberlite, lamproite and carbonatite magmas. In this paper, we report the melting phase relationships of aphanitic group II kimberlite composition up to 9 GPa and melt compositions determined using aggregates of diamond grains at 7 GPa .

Melting experiment of aphanitic group II kimberlite

Melting phase relations of aphanitic group II kimberlite have been studied in the pressure up to 9 GPa. The starting composition chosen for this study is group II aphanitic kimberlite (173/24/K19/57) from Makganyene Mine, South Africa. This composition is characterized by higher SiO_2, K_2O, Al_2O_3 and Ba than the average group I kimberlite composition (Shee et al., 1989). X_{CO_2} ($CO_2/(CO_2+H_2O)$ ratio) is 0.59. A multi-anvil high pressure apparatus at Tohoku University and a 1/2 inch diameter 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 graphite heater.

The liquidus temperature is determined about 1470°C at 6 GPa and 1520°C at 8 GPa (Fig. 1). Suprasolidus phase assemblage at 1400°C varies with elevating pressure as; Phl + Liq, Phl + Cpx + Liq, Phl + Cpx + Opx + Liq, Cpx + Opx + Gt + Liq, Cpx + Gt + Liq. Phlogopite breakdowns between 1300-1400°C and 6-7 GPa by the reaction Phl + Cpx = Gt + Liq. Phlogopite is not a stable phase above 6-7 GPa at 1300-1400°C. Neither stable K-bearing, hydrate-, nor carbonate-crystalline phase were observed in the run products above 7 GPa. The data suggest that the aphanitic group II kimberlite magma can be equilibrated with eclogitic assemblage above 6.5 GPa, with phlogopite-peridotitic assemblage at 6.5-7 GPa at 900°C.

Determination of melt composition

Melt compositions in the run products at relatively low temperatures are multiply saturated with silicate phases. Low abundances of these melt phases in the run products hamper the precise determination of their composition using microprobe analyses. In this study, an attempt was made to separate melt formed by partial melting of kimberlite into pore space between diamond grains at high pressures. Diamond powder (3 μ m in diameter) was packed on top of tightly packed kimberlite powder (the ratio of diamond to kimberlite is 1:2). In the selected run, the charges were loaded in graphite capsules. The graphite capsule, then loaded in sealed Pt capsules.

Melt compositions in the run products at 7 GPa were determined by analyzing melt phase trapped in interstitial area between diamond grain (Table 1). The melts analyzed are in equilibrium with Ol + Opx + Cpx + Phl (phlogopite) + Ap (apatite) at 900°C, and Opx + Cpx + Gt above 1100°C (Fig. 1). Run products were polished by diamond powder without a water and analyzed with a scanning

microprobe (JEOL-JSM-5300) with Link EDS system. Analytical conditions were 15 KV accelerating voltage and 120 x 90 μ m spot area.

Chemical characteristic of melt

Melts in the runs at 7 GPa are extremely enriched in K_2O, H_2O and CO_2 and depleted in SiO_2 (Table. 1). The analyses indicate that SiO_2 and Al_2O_3 in melts decrease with decreasing temperature, while K_2O in melts increases with decreasing temperature. No P_2O_5-bearing crystalline phase exists in the run products above 1100°C but in the run at 900°C apatite is a stable phase. Based on mass balance calculation, we estimate proportion of melt in each run product and H_2O and CO_2 contents in the melts at various temperatures (Table 1).

Composition of melts in this study are broadly similar to those reported from diamond inclusions by Navon et al. (1988) and Schrauder and Navon (1994)(Fig. 2). It is noted that dolomitic melt (Mg/(Mg+Ca) = 0.52) coexists with a phlogopite-bearing peridotitic assemblage at 900°C and 7 GPa. This result is consistent with recent melting experimental results in the magnesite-diopside system (Arima and Presnall, 1995), and those in the $CMASCO_2$ system from 3.0-7.0 GPa (Dalton and Presnall, 1998). Melts enriched in CO_2, K_2O, and H_2O might account for kimberlite- and lamproite-magma genesis, diamond growth in subcratonic mantle, and mantle metasomatism near asthenosphere-lithosphere boundary.

Reference

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Table 1. Chemical compositions of aphanitic group II kimberlite and melts formed by partial melting

	1	2	3	4	5
SiO2	40.90	3.34	9.08	28.79	36.17
TiO2	1.00	0.17	2.24	2.21	1.22
Al2O3	5.28	1.05	0.89	2.74	4.88
FeO	8.43	4.57	4.44	2.39	6.72
MnO	0.24	0.17	0.00	0.00	0.00
MgO	18.44	7.77	10.93	14.69	13.31
CaO	9.37	9.88	7.05	8.70	6.89
Na2O	1.22	3.16	1.94	0.71	1.26
K2O	5.92	28.09	29.16	11.15	9.34
P2O5	1.09	0.40	3.79	3.11	2.26
BaO		0.40	0.40	0.82	-----
CO2*	6.70	31.79	23.33	19.14	13.92
H2O*	1.94	9.21	6.75	5.54	4.03
total	100.53	100	100	100	100

1. Aphanitic group II kimberlite used as starting material.
2. 100 % normalized melt formed at 900 °C (Apdia-13**)
3. 100 % normalized melt formed at 1100 °C (Apdia-9**)
4. 100 % normalized melt formed at 1300 °C (Apdia-1)
5. 100 % normalized melt formed at 1350 °C (Apdia-7**)
* CO2 and H2O calculated by K2O or P2O5
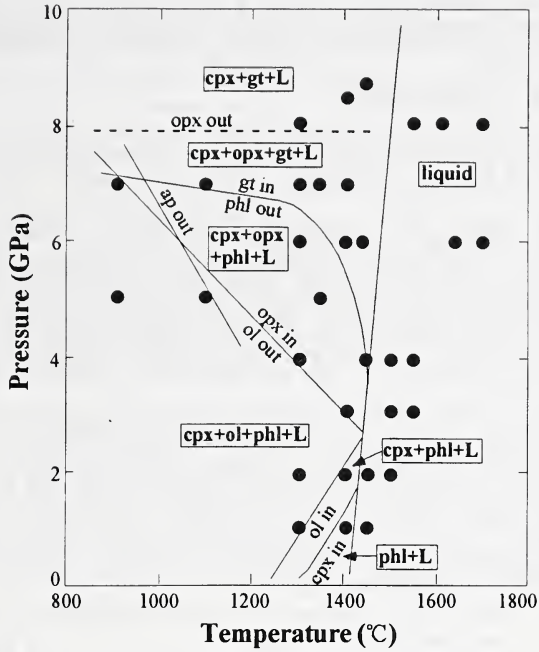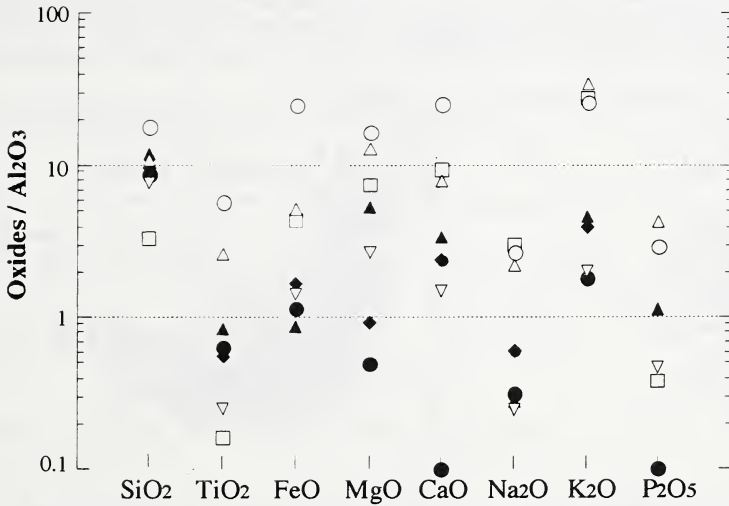** 2, 3 and 5 were used Pt and graphite double capsule

Fig.1 Phase diagrum of aphanitic group II kimberlite

● Compositional endmember of hydrous fluid in Botswanan diamond (Schrauder and Navon, 1994)
○ Compositional endmember of carbonatitic fluid in Botswanan diamond (Schrauder and Navon, 1994)
◆ Average composition of diamond inclusion fluid (Navon at al., 1988)
□ Apdia-13 (900 ℃)
△ Apdia-9 (1100 ℃)
▲ Apdia-1 (1300 ℃)
▽ Apdia-7 (1350 ℃)

Fig.2 Oxides/Al2O3 ration in the melts.

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