PARTIAL MELTING OF PHLOGOPITE-BEARING SYNTHETIC SPINEL- AND GARNET-LHERZOLITES

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The principal mineral phases of phlogopite-garnet or spinel-lherzolite appear in the six component model system CaO-K2O-MgO-Al2O3-SiO2-H2O (CKMASH) as phlogopite, spinel, pyrope-rich garnet, spinel, forsterite, enstatite and diopside.

An interpretation of results at 15 kb is presented in fig 1 which is a projection of starting compositions into the system CaO-Al2O3-K2O (CAK) from MgO, SiO2 and H2O (forsterite, enstatite and vapour) showing the nature of the additional crystalline phases (diopside, phlogopite or spinel) which will crystallize from the starting compositions, forsterite, enstatite and vapour already being present. Boundaries between the fields where diopside, phlogopite or spinel is the additional crystalline phase are shown, with an indication of the uncertainty in their location. The compositions studied are indicated. The unique liquid which is in simultaneous equilibrium with forsterite, enstatite, diopside, spinel, phlogopite and water-rich vapour has been located and its proportions of CaO: Al2O3:K2O read from the diagram (table 1, row 1). The geometric average composition from the uncertainty triangle is quoted.
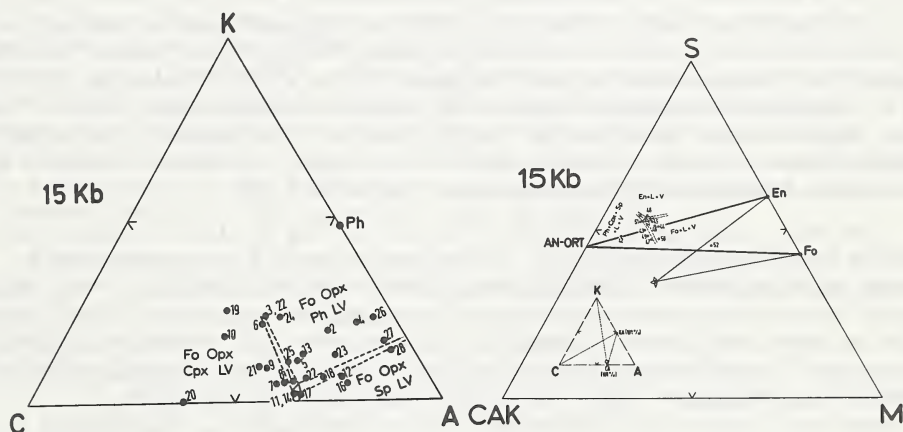

Fig 1. CaO-Al2O3-K2O diagram (wt%) showing projection of the forsterite, enstatite and vapour saturated liquidus surfaces in the system CKMASH at 15 kb.

Fig 2. (CaO$_{33.4}$Al2O3$_{63.6}$K2O$_{3.0}$)-MgO-SiO2 system at 15 kb.

Compositions were synthesised using the appropriate C:A:K proportions (from fig 1) in a system (C:A:K). M.S. The boundaries of the fields in which forsterite, enstatite or diopside+phlogopite+spinel appear at the liquidus in the presence of water-rich vapour in this system were then determined (fig 2) and the unique liquid composition in simultaneous equilibrium with forsterite, enstatite, diopside, phlogopite, spinel and water-rich vapour read off (table 1, row 3) and converted to oxide weight percentages (table 1, row 5). The CIPW norm of this liquid is presented in table 2, row 1.

Table 1

Compositions (wt% proportions, water-free) of liquids in isobaric invariant equilibria with phlogopite-bearing spinel- or garnet-lherzolite in the presence of water-rich vapour.

			CaO	Al_2O_3	K_2O	MgO	SiO_2
1)	15 kb	$980 \pm 10^{\circ}C$	33.4	63.6	3.0		
2)	30 kb	$1080 \pm 10^{\circ}C$	33.2	54.5	12.3		
3)	15 kb	$980 \pm 10^{\circ}C$		35.5		11.5	53.0
4)	30 kb	$1080 \pm 10^{\circ}C$		29.5		18.0	52.5
5)	15 kb	$980 \pm 10^{\circ}C$	11.9	22.6	1.0	11.5	53.0
6)	30 kb	$1080 \pm 10^{\circ}C$	9.8	16.1	3.6	18.0	52.5

Table 2

CIPW norms of isobaric invariant liquids in equilibrium with water-rich vapour and phlogopite-bearing spinel or garnet lherzolite.

			Qz	Or	An	Di	Hy	Ol
1)	15 kb	$980 \pm 10^{\circ}C$	6.5	6.3	58.5	0.2	28.5	-
2)	30 kb	$1080 \pm 10^{\circ}C$	-	21.5	33.1	12.0	19.5	13.8

In fig 2 the heavy triangle links the compositions of enstatite and forsterite to the point on the SiO_2-$(CaO+K_2O+Al_2O_3)$ join where the CIPW norm of the composition is just saturated with silica (labelled An-Ort in fig 2; negligible diopside appears in this particular CAK ratio). The inset figure shows that the CAK proportions of the isobaric invariant liquid (small circle) are such that it is almost corundum-normative and far remote from peralkaline character (because $K < A$).

The more lightly delineated triangle in fig 2 links forsterite, enstatite and the piercing point in this section of the join diopside $(CaMgSi_2O_6)$-phlogopite$(K_2Mg_6Al_2Si_6O_{20}(OH)_4)$-spinel$(MgAl_2O_4)$. The area inside this triangle represents the intersection with this composition plane of the subsolidus phlogopite-spinel-lherzolite mineral assemblage. The unique liquid with which it coexists at 15 kb has a composition lying outside this region. There will be a reaction relationship:-

    forsterite+liquid $\rightleftharpoons$ enstatite+diopside+phlogopite+spinel+vapour - I

in the isobaric invariant equilibrium. If a phlogopite-spinel-lherzolite containing excess water vapour were to be partly melted at 15 kb, the initial liquid, if isolated and fractionally crystallized, would precipitate mineral assemblages resembling phlogopite-spinel websterite, containing no forsterite, and the residual liquids would become yet richer in normative quartz.

The initial liquid composition produced by partial melting has affinities with andesitic and high alumina basalt melts particularly in high quartz, anorthite and low diopside in the CIPW norm (table 2).

Results at 30 kb are presented in figs 3 and 4 and in tables 1 (rows 2, 4 and 6) and table 2 (row 2). The isobaric invariant liquid in equilibrium with phlogopite+garnet+diopside+enstatite+forsterite+vapour at 30 kb, although relatively rich in SiO_2, has higher MgO than at 15 kb, and there is substantial olivine, diopside and orthoclase in the CIPW norm. The liquid is far from being critically undersaturated in silica or peralkaline in character.
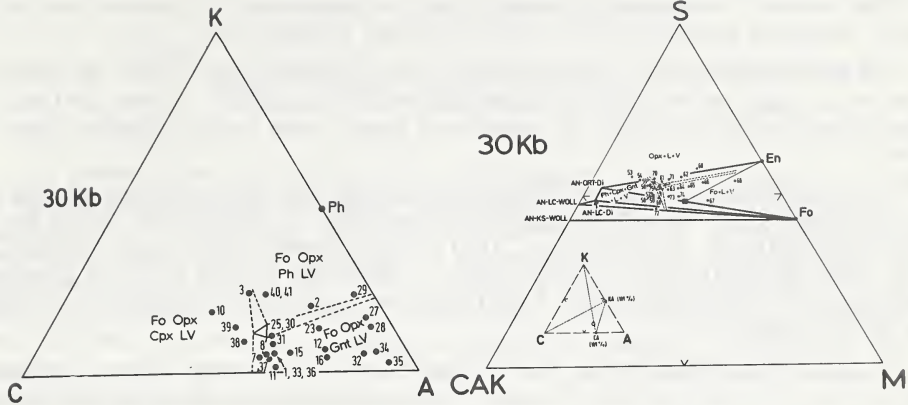
Bravo and O'Hara

Fig 3. CaO–Al$_2$O$_3$–K$_2$O diagram (wt%) showing projection of the forsterite, enstatite and vapour saturated liquidus surfaces in the system CKMASH at 15 kb.

Fig.4. (CaO$_{33.2}$Al$_2$O$_{354.5}$K$_2$O$_{12.3}$)–MgO–SiO$_2$ system at 30 kb.

In fig 4 the heavy lines connect forsterite to the compositions within the system whose CIPW norms contain anorthite, orthoclase and diopside only (An-Ort-Di); anorthite-leucite-diopside (An-Lc-Di); anorthite-leucite-wollastonite (An-Lc-Woll) and anorthite-kalsilite-wollastonite (An-Ks-Woll). Enstatite is connected to the first of these piercing points and the heavily outlined triangles depict the compatibility assemblages in the CIPW norm as bulk compositions become increasingly undersaturated in silica within this system.

Also shown, and linked to enstatite and forsterite by light lines, is the piercing point in this section of diopside (CaMgSi$_2$O$_6$)–pyrope (Mg$_3$Al$_2$Si$_3$O$_{12}$)–phlogopite(K$_2$Mg$_6$Al$_2$Si$_6$O$_{20}$(OH)$_4$). The area within this triangle represents the intersection with this composition section of the subsolidus phlogopite-garnet-lherzolite mineral assemblage. The unique liquid with which it coexists at 30 kb under water saturated conditions has a composition lying outside this region and there will be a reaction relationship:-

forsterite+liquid $=$ enstatite+diopside+phlogopite+garnet+vapour – II
in the isobaric invariant equilibrium.

If a phlogopite-garnet-lherzolite containing excess water vapour were to be partly melted at 30 kb, the initial liquid, if isolated and fractionally crystallized,would precipitate mineral assemblages resembling phlogopite-enstatite-eclogite or phlogopite-eclogite and the residual liquids would trend towards oversaturation in silica.

The initial liquid composition produced by partial melting at 30 kb has no affinities with common eruptive magmas, and like the liquid formed at 15 kb, it bears no resemblance to any suggested kimberlite fluid.

If kimberlite fluids are small scale partial melting products of phlogopite-bearing peridotites, the process must be assigned to greater pressures than 30 kb, or postulated to occur in the absence of a vapour phase, or in the presence of a vapour phase containing substantial

amounts of CO_2 etc.

The extract required to modify the 30 kb liquid to become the 15 kb liquid consists essentially of diopside and phlogopite.

In the presence of a water-rich vapour, enstatite is not in equilibrium with liquids critically undersaturated in silica in the system $CaO-K_2O-MgO-Al_2O_3-SiO_2-H_2O$ at pressures below some value greater than 30 kb.

In the K_2O free system CMASH the temperature of beginning of melting of water-saturated spinel- or garnet-lherzolite is $1000^O\pm10^OC$ at 10 kb (Yoder and Chinner, 1960; Yoder, 1971; Ford unpublished), and 1000 ± 5^OC at 15 kb (new determination, Bravo 1973). Addition of K_2O to this alumina oversaturated system has very little effect upon the temperature of beginning of melting.

Unlike the situation in dry systems where garnet-pyroxene assemblages constitute a thermal divide between olivine-saturated and quartz-saturated liquids, fig 4, and reaction relationship II show that phlogopite-bearing eclogites with excess water melt 'incongruently', yielding olivine-bearing residua. The complementary liquids do not of course resemble kimberlite.

References

Yoder, H.S.,Jr. 1971. Yb. Carnegie Inst. Wash., 69, 176-181.
Yoder, H.S.,Jr. and Chinner, G.A. 1960. Yb. Carnegie Inst. Wash. 59, 78-81.