PRIMARY AND SECONDARY PHLOGOPITES AND CLINOPYROXENES IN GARNET LHERZOLITE XENOLITHS

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As garnet lherzolites are the most common ultramafic xenolith type in the majority of kimberlite pipes (Mathias et al 1970), they appear to represent the predominant rock type in the regions of the upper mantle from which kimberlite originates or through which it passes during its emplacement into the crust. It is thus a reasonable proposition that the primitive upper mantle material, from which basalt magmas are derived, has a mineral and overall chemical composition largely similar to the standard garnet lherzolite xenoliths of the type previously analysed and described by Carswell and Dawson (1970).

Whilst the major element chemistry of the postulated primitive upper mantle material has now been fairly well established, whole rock analyses of garnet lherzolite xenoliths do not provide reliable figures of K_2O and H_2O due to the growth of secondary phlogopite, amphibole, and serpentine. It is therefore necessary to deduce the likely K_2O and H_2O values from a consideration of the primary mineralogy and mineral chemistry of these xenoliths.

Although phlogopite is only present as a minor phase in garnet lherzolite xenoliths, petrographic examination suggests the common presence of two generations of phlogopite growth. On the one hand it forms rare, large discrete plates, showing no apparent textural evidence of being in disequilibrium with the other primary minerals and hence thought itself to be primary. In addition it forms generally narrow rims around some garnets, where it is undoubtedly of secondary growth.

The phlogopites in six South African garnet lherzolite xenoliths were therefore analysed with an electron microprobe to see if significant chemical distinctions exist between the postulated primary and secondary phlogopites, and the analyses are presented in Tables 1 and 2.

Each of the analyses listed is an average of from two to six analyses of appropriate phlogopite grains in the xenolith in question. In the majority of cases the internal variation in the group of analyses averaged was strikingly small, and in fact it is apparent that there is little variation in composition within the groups of primary and secondary phlogopites from the different xenoliths. However, the primary phlogopites as a group have significantly lower TiO_2, Cr_2O_3 and Al_2O_3 contents, lower Fe^{2+}/Mg^{2+} and Na^+/K^+ ratios, and higher SiO_2 contents than the secondary phlogopites. They also have much lower TiO_2 contents and Fe^{2+}/Mg^{2+} ratios than the previously postulated primary upper mantle phlogopites from a Lashaine garnet lherzolite xenolith (Dawson et al 1970) and from Jan Mayen alkali basalts (Flower 1971). They are therefore thought more likely to represent a primary phase in equilibrium with the four phase garnet lherzolite assemblage in the upper mantle than the Lashaine and Jan Mayen phlogopites.

Recent experimental data (Yoder and Kushiro 1969; Modreski and Boettcher 1972) has indicated that the stability field of phlogopite is likely to extend down into the upper mantle - perhaps to depths as great as 150-200 kms. in continental regions with low geothermal gradient.

The presence of on average 1% by volume of primary phlogopite in the garnet lherzolite xenoliths studied, thought to have originated from depths of 100-150 kms., suggests that the primitive upper mantle material at such depths may contain on average about 0.10 wt.% K_2O and 0.03 wt. % H_2O.

An interesting petrographic feature of the clinopyroxenes in all six xenoliths studied, except CB6, is the existence in most grains of rather cloudy 'porous' outer zones around clear pale green cores. These 'porous' rims are variable in width even in the same grain and in places cut right across the grains and almost completely replace the original clinopyroxene.

Both the clear primary clinopyroxene cores and the cloudy 'porous' clinopyroxene rims have been analysed by electron microprobe and the critical chemical features are summarised in Tables 3 and 4.

By far the most striking difference in composition between the clear clinopyroxene cores and the cloudy margins is the decrease in the Al_2O_3 and Na_2O contents in the latter, reflected in the much lower percentage of jadeite molecule. On the other hand differences in Cr_2O_3 are negligible and in Ca/Ca+Mg ratio only minimal - corresponding to equilibrium temperatures only some 20-80^oC lower for the rims than the cores, on the basis of the solid solution limits in the synthetic diopside-enstatite system at 30 kbs. pressure (Davis and Boyd 1966).

No additional Na_2O and Al_2O_3 rich phase such as plagioclase was detected to be associated with the jadeite depleted clinopyroxene rims, at least in amounts resolvable with the microprobe. It seems most likely that the Na_2O and Al_2O_3 released, possibly as a consequence of the pressure decrease during kimberlite emplacement, has been taken up in both the secondary phlogopite and amphibole. It is noteworthy that the secondary phlogopites have higher Na^+/K^+ ratios than the primary phlogopites.

References:

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TABLE 1 - Primary Phlogopites

Wt.%	CK1	CK2	CK3	CK4	CB6
SiO_2	40.73	41.24	41.10	41.54	41.67
TiO_2	00.28	00.22	00.15	00.26	00.68
Al_2O_3	12.81	12.39	13.24	12.47	12.20
Cr_2O_3	00.86	00.70	00.60	00.75	00.61
*FeO	02.63	02.64	02.56	02.52	02.78
MnO	00.01	00.05	00.01	00.03	00.02
MgO	26.52	26.55	27.87	26.53	26.49
CaO	00.02	00.02	00.02	00.01	00.01
Na_2O	00.75	00.76	00.99	00.91	00.31
K_2O	09.31	09.32	08.78	09.16	10.21
TOTAL	93.92	93.89	95.32	94.16	94.98
Fe^{2+}/Mg^{2+}	0.056	0.056	0.051	0.053	0.059
Na^+/K^+	0.123	0.124	0.172	0.151	0.046

*FeO - Total Iron as FeO

TABLE 2 - Secondary Phlogopites

Wt.%	CK1	CK3	CK4	CB4	CB6
SiO_2	39.69	39.04	39.22	39.06	39.33
TiO_2	01.45	00.45	00.86	01.36	01.41
Al_2O_3	13.93	16.06	14.54	15.13	14.81
Cr_2O_3	01.60	01.51	01.36	01.57	01.50
*FeO	03.12	03.15	03.17	02.95	02.90
MnO	00.10	00.02	00.14	00.05	00.02
MgO	24.83	25.27	24.48	25.10	24.67
CaO	00.03	00.02	00.03	00.02	00.03
Na_2O	00.92	01.41	01.82	01.05	00.92
K_2O	09.06	07.87	07.38	08.41	09.14
TOTAL	94.73	94.80	93.00	94.70	94.73
Fe^{2+}/Mg^{2+}	0.070	0.070	0.073	0.066	0.066
Na^+/K^+	0.154	0.272	0.376	0.189	0.153

*FeO - Total Iron as FeO

TABLE 3 - Primary Clinopyroxene Cores

Wt.%	CK1	CK2	CK3	CK4	CB4	CB6
Al_2O_3	3.37	3.48	3.39	2.30	4.63	2.54
Cr_2O_3	1.89	1.64	1.85	1.61	2.69	1.62
Na_2O	2.74	3.12	3.09	2.08	4.02	2.33
%Jadeite	9.0	13.5	8.8	4.7	13.8	3.6
Ca/Ca+Mg	0.471	0.462	0.472	0.477	0.477	0.458

TABLE 4 - Cloudy Clinopyroxene Rims

Wt.%	CK1	CK2	CK3	CK4	CB4
Al_2O_3	2.31	1.43	2.30	1.26	3.44
Cr_2O_3	1.76	1.82	1.82	1.60	2.65
Na_2O	2.24	1.76	2.19	0.96	2.29
%Jadeite	2.6	4.1	3.5	0.3	6.5
Ca/Ca+Mg	0.482	0.471	0.477	0.501	0.470