

KIMBERLITE POTASSIC RICHTERITE AND THE DISTRIBUTION OF POTASSIUM IN THE UPPER MANTLE

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The occurrence of the rare amphibole potassic richterite (magnophorite), which has the generalised formula $\text{KNaCaMg}_5\text{Si}_8\text{O}_{22}(\text{OH},\text{F})_2$, in kimberlite materials was first noted by Erlank and Finger (1970), who identified potassic richterite in a phlogopite nodule from the Wesselton kimberlite. Subsequent work has revealed the existence of potassic richterite in an ultrabasic hypabyssal rock with kimberlite affinities and in four lherzolite nodules; for convenience this report will refer to Types A, B, and C potassic richterite respectively to denote the separate modes of occurrence involved. Representative electron microprobe analyses of each type are given in Table 1; as shown, they may be well expressed in the amphibole formula. The varieties studied are generally colourless, with slight and variable pale pink to pale green pleochroism, and it is likely that potassic richterite has been overlooked or misidentified as orthopyroxene in previous studies. The analyses in Table 1 are reasonably similar and agree in a general way with analyses of potassic richterite from potassium-rich lavas in the West Kimberley area, Australia (Prider, 1939) and in the Leucite Hills, Wyoming (Carmichael, 1967). However, the latter types have markedly higher TiO_2 contents (3.5-6.2% TiO_2) than the kimberlitic varieties indicated in Table 1. Kushiro and Erlank (1970) showed that although potassic richterite, in the presence of water, is stable to 30 kb at 1100°C, the recrystallized products had much lower TiO_2 contents than the starting material, which was from the type locality in Australia (Prider, 1939). It is to be noted that all potassic richterites analysed to date are characterized by an Al deficiency, i.e. there is insufficient Al to make up the tetrahedral sites to 8 with Si, and thus it is assumed that some Ti is present in fourfold co-ordination. Specific comments related to the three types follow:

TYPE A potassic richterite is present in several phlogopite nodules or aggregates, which are usually mainly composed of phlogopite. Varying amounts of chrome-diopside are present; one nodule which has roughly equal proportions of phlogopite and diopside has a layered appearance. The first occurrence of potassic richterite noted by Erlank and Finger (1970) was in the form of 100 μm inclusions contained within diopside from a nodule from the Wesselton mine; larger (500 μm in diameter) and discrete grains have since been observed in a nodule from the Du Toitspan mine. The origin of these unusual nodules is enigmatic, possibly they are high pressure cumulates from a fractionated magma or the products of limited degrees of partial melting.

TYPE B potassic richterite has been found in a medium grained ultramafic hypabyssal rock from Bester's mine, Pniel Estate, Barkly West. Large partly rounded and corroded olivine crystals (Fo_{90}) are set in a matrix of euhedral phlogopite, potassic richterite and clinopyroxene, and accessory olivine, calcite and opaque mineral. The major element composition of this rock overlaps that shown by published analyses of kimberlite (e.g. 43% SiO_2 , 31% MgO , 3.8% K_2O) and it is also characterized by relatively high concentrations of both ferromagnesian and incompatible elements (1980 ppm Cr, 1460 ppm Ni, 1010 ppm Ba, 160 ppm Rb).

TABLE 1 CHEMICAL COMPOSITION OF POTASSIC RICHTERITES (wt.%)

	Type A (WESS 156)	Type B (Pn 1)	Type C (JYG 360)
SiO ₂	54.29	55.60	54.92
TiO ₂	0.59	0.88	0.57
Al ₂ O ₃	1.24	0.44	1.70
FeO	4.31	4.52	2.31
MnO	0.07	0.03	0.01
MgO	21.16	21.43	22.52
CaO	7.12	5.81	6.70
Na ₂ O	3.24	4.04	3.84
K ₂ O	4.72	4.88	4.61
Cr ₂ O ₃	0.06	0.15	0.89
Total	96.80	97.78	98.07

NUMBER OF CATIONS FOR 23 OXYGENS

Si	7.770)	7.870)	7.697)
Al	0.209)8.000	0.074)8.000	0.281)8.000
Ti	0.021)	0.056)	0.022)
Ti	0.043)	0.038)	0.038)
Mg	4.514)	4.522)	4.705)
Cr	0.006)5.000	0.016)5.000	0.098)5.000
Fe	0.437)	0.424)	0.159)
Fe	0.078)	0.111)	0.112)
Mn	0.008)	0.003)	0.002)
Ca	1.091)2.000	0.881)2.000	1.006)2.000
Na	0.823)	1.005)	0.880)
Na	0.077)	0.103)	0.163)
K	0.862)0.939	0.881)0.984	0.824)0.987

It differs in composition from other potassic richterite bearing lavas (jumillites, wolgidites, orendites etc) notably by its lower K₂O and higher MgO content and lack of feldspar and feldspathoid. Small degrees of partial melting are presumably involved in the production of all these K-rich lavas.

TYPE C potassic richterite has thus far been identified in four Therszolite nodules (2 from the Bultfontein, and 1 each from the DuToitspan and Monastery mines). Olivine is the dominant constituent in each type, with variable amounts of enstatite, chrome-diopside, potassic richterite and phlogopite comprising the other essential minerals. These rocks are coarse grained and locally contain patches of diopside, potassic richterite and phlogopite. Their altered nature does not readily allow textural evaluation, but the potassic richterite, although a late

crystallizing phase, clearly shows equilibrium relationships with olivine, diopside and phlogopite. Trace element analyses (XRF) of three of the lherzolites show, as expected from their mineralogy, high abundance of the incompatible elements when compared to granular and sheared nodules which do not contain potassic richterite, with the latter types exhibiting the greatest depletion. This may be especially illustrated by the refractory elements Zr and Nb, viz:

	<u>Zr, ppm</u>	<u>Nb, ppm</u>
Potassic Richterite bearing lherzolites	42,169,82	17,17,36
Granular nodules	6-21	2-6
Sheared nodules	2-10	1-3

High pressure work by Kushiro and Erlank (1970) showed that although potassic richterite is by itself and in the presence of diopside stable under upper mantle conditions, it is not stable in the presence of garnet with which it reacts to form phlogopite. The bulk rock chemistry, and the alumina deficiency in the calculated mineral formulae show that potassic richterite crystallizes in an environment in which the chemical potential of K is high relative to that of Al. Only one of the rocks studied here (Monastery mine) contains garnet, present in trace amounts in the form of small rounded grains enclosed by enstatite. Whatever the origin of the potassic richterite bearing rocks discussed here, it appears that they are derived from a locale in which garnet or aluminous spinel are not present or do not participate in their development, or from liquids which have high K/Al ratios. Thus the potassic richterite bearing lherzolites, while mantle derived and equilibrated as shown by pyroxene compositions, are not considered to be representative of upper mantle materials and special conditions are required for their formation.

As shown above, potassic richterite is not likely to be an important mantle phase. Electron microprobe studies have shown that much of the K present in kimberlite nodules is secondary in origin, being located in cracks, along grain boundaries, reaction rims and alteration products (Erlank, 1970). Olivine, orthopyroxene and garnet contain <30 ppm K as measured by microprobe analysis; higher concentrations reported in the literature measured on separated fractions indicate the separates to be impure. The K concentration of clinopyroxenes is variable; up to 500 ppm K is found in chrome-diopside and up to 1500 ppm K in eclogitic omphacite. These concentrations, taken in conjunction with average modal mineralogy for four phase garnet lherzolite and predicted upper mantle concentrations using independent approaches indicate that phlogopite (0.5 - 1%) is the most likely upper mantle potassic phase. This conclusion may have been expected from simple thin section examination of kimberlite nodules, but textural relationships do not indicate what proportion of the phlogopite now observed in kimberlite nodules is an original pre-melt constituent of the upper mantle. It is considered that much of the phlogopite in kimberlite nodules is equilibrated under upper mantle conditions, but has formed by either metasomatic processes or represents trapped partial melt.

Available evidence suggests that in shield regions phlogopite should be stable to depths of about 175 km (Modreski, 1972). Below this depth

the distribution of K in the mantle is not well known, but it is likely that clinopyroxene is an important phase, partly because of the lack of a potassium mineral but also because there is some evidence to show that the K content of clinopyroxene is temperature and pressure dependant. Thus electron microprobe measurements show that:

- (a) clinopyroxene from intrusive and extrusive igneous rocks (Bushveld gabbros and Karroo dolerites) and from xenoliths in basaltic lavas (Hawaii) and volcanic breccias (Kakanui, Delegate) contain < 50 ppm K.
- (b) calcic diopsides from kimberlite nodules contain < 250 ppm K while sub-calcic diopsides, equilibrated at higher temperatures (Boyd, 1973), contain up to 500 ppm K.
- (c) eclogitic omphacites contain up to 1500 ppm K; the distribution of K in these minerals may be bimodal (Erlank, 1970). Omphacite from diamond apparently contains up to 2200 ppm K (Sobolev, 1972).
- (d) synthetic clinopyroxenes produced at high temperatures and pressures show that < 150 ppm K enters the clinopyroxene structure at pressures of up to 30 kb (Erlank and Kushiro, 1970). However, at higher pressure more K is apparently able to substitute in clinopyroxenes, 2200 ppm K being measured in a synthetic clinopyroxene produced at 100 kb and 1400°C (Shimizu, 1971).

Thus, at depths below which phlogopite is stable, and unless K is contained in interstitial melts or other potassium minerals, clinopyroxene is likely to be an important phase for controlling the distribution of K in rocks and basaltic melts at these depths.

References:

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| Boyd, F.R. (1973) | Geochim. Cosmochim. Acta. (in press). |
| Carmichael, I.S.E. (1967) | Cont. Mineral Petr. <u>15</u> , 24-66. |
| Erlank, A.J. (1970) | Carnegie Inst. Wash. Yr. Book <u>68</u> , 433-439. |
| Erlank, A.J. and Finger, L.W. (1970) | Carnegie Inst. Wash. Yr. Book <u>68</u> , 442-443. |
| Erlank, A.J. and Kushiro, I. (1970) | Carnegie Inst. Wash. Yr. Book <u>68</u> , 439-442. |
| Kushiro, I., and Erlank, A.J. (1970) | Carnegie Inst. Wash. Yr. Book <u>68</u> , 231-233 |
| Modreski, P.J. (1972) | Carnegie Inst. Wash. Yr. Book <u>71</u> , 392-396. |
| Prider, R.T. (1939) | Mineral. Mag. <u>25</u> , 373-387. |
| Shimizu, N. (1971) | Earth Planet. Sci. Lett. <u>11</u> , 374-380. |
| Sobolev, N.V. (1972) | 24th Int. Geol. Congress, Section 2, 297-302. |