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Cr-rich spinel and garnet in two peridotite xenoliths from the Frank Smith mine South Africa: Significance of Al and Cr distribution between spinel and garnet

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ABSTRACT. Peridotite xenoliths 73-106 and 73-109 have coarse textures. All minerals in 73-106 are very Ti-rich, and include olivine (Fo 87.6), orthopyroxene (En 90.0), garnet (core TiO_2 0.8, Cr_2O_3 7; rim 1.4, 4 wt. %), spinel (TiO_2 5, Cr_2O_3 38), clinopyroxene (Al_2O_3 1-8) secondary mica (TiO_2 6, Cr_2O_3 2.5 near garnet 0.5 away from garnet), and serpentine (FeO 5-12) enclosing perovskite-rimmed ilmenite and minute apatites. All minerals in peridotite 73-109 are Ti-poor, and include olivine (Fo 92.6), orthopyroxene (En 93.6), garnet (Cr_2O_3 3.1-3.8), spinel (55), ureyitic diopside, primary mica (TiO_2 0.06, Cr_2O_3 1.0, BaO 0.5, Cl 0.04), and serpentine (FeO 2-23). Various thermometers indicate ~ 1350K (73-106) and 1100K (73-109). The low Al_2O_3 in the orthopyroxenes gives 39-47 kb for 73-109 from the Wood-Banno barometer. In 73-106, the spinel lies in secondary mica next to the garnet rim, whereas the spinel of 73-109 occurs in grains enclosed by garnet. The former assemblage indicates diffusion-dependent disequilibrium, whereas the latter is attributed to simultaneous growth of spinel and garnet, perhaps consequent upon exsolution from orthopyroxene. Complex behaviour was found for the Cr/Al distribution in published analyses of garnet and spinel. The 73-109 pair lies near the Thaba Putsoa trend, and the 73-106 assemblages are displaced towards the kelyphite region in which garnet and spinel have similar Cr/Al. Spinel and garnet may coexist over a 30 kb pressure interval ranging from ~ 16 kb for low bulk Cr to ~ 40 kb for high Cr.

DETAILED study of the texture and mineral chemistry of peridotite xenoliths can provide information on the physical and chemical nature of the upper mantle. Complex textural relationships between garnet, Al,Cr-spinel, and silicates testify to incomplete accommodation to changing physical conditions (Aoki and Prinz, 1974; Basu and MacGregor, 1975; Dawson *et al.*, 1978; Reid and Dawson, 1972; Reid *et al.*, 1975). Occurrence of spinel in kelyphitic coronas around garnet is particularly common, but only a few specimens (Lock and Dawson, 1980) have escaped metasomatism which has removed or obscured important textural information. The transition from the spinel- to the garnet-peridotite facies is an important control in the upper mantle (O'Hara *et al.*, 1971), but its position depends greatly on the bulk Cr/Al ratio. Whereas the transition from spinel- to garnet-peridotite occurs in the $CaO-MgO-Al_2O_3-SiO_2$ system near 15 kb at 1200 K and about 20 kb for 1600 K (data collected in Jenkins and Newton, 1979), replacement of half the Al_2O_3 by Cr_2O_3 raises the pressure by about 16 kb (MacGregor, 1970, fig. 4; see also Wood, 1977), and of all the Al_2O_3 by ~ 28 kb (O'Neill, 1981). Although *coarse* grains of garnet and spinel tend to be mutually exclusive in peridotite xenoliths, the following papers report coexisting assemblages: Boyd and Nixon (1978), Kimberley, S. Africa; Carswell *et al.* (1979) and Mitchell *et al.* (1980), Pipe 100, Lesotho; Danchin (1979), Premier, S. Africa; Ferguson *et al.* (1977), NSW, Australia; MacGregor (1979), Kao, Lesotho; Nixon and Boyd (1973), Thaba Putsoa and Mothae, Lesotho; Smith and Dawson (1975), Matsoku; Nixon and Boyd (1979), Malaita, Solomon Islands: Sobolev (1977), occurrences in Russia. Spinel and garnet pairs in alkremites (Nixon *et al.*, 1978), and in a spinel-garnet websterite (Irving, 1974) were not considered because their bulk compositions are much richer in Al and Ca, and lower in Cr, than typical ultramafic peridotites, and because they lack the olivine and pyroxene of lherzolite assemblages.

We describe coexisting spinel and garnet in two peridotite xenoliths from the Frank Smith mine, Bellsbank, S. Africa. Associated micas are significant for storage of K in the mantle. The xenoliths 73-106 and 73-109 were collected by JVS from a

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TABLE I. Electron microprobe analyses of 73-106

	1	2	3	4	5	6	7	8	9	10	11	12	13
P_2O_5	0.06	0.03	0.01	nd	nd	nd	nd	nd	-	-	nd	-	-
SiO_2	41.2	42.2	39.6	57.1	54.5	48.1	37.5	37.8	34.3	40.5	0.16	0.6	0.5
TiO_2	0.84	1.36	0.03	0.19	0.1?	1.7	5.7	5.6	-	-	5.14	51.0	54.5
Al_2O_3	18.1	19.6	0.02	0.76	1.7	7.8	14.4	14.7	0.6	0.4	16.2	0.4	0.7
Cr_2O_3	6.7	3.6	0.04	0.34	1.3	2.2	2.5	0.5	-	-	38.2	0.8	nd
Fe_2O_3	-	-	-	-	-	-	-	-	-	-	5.6	10.7	-
FeO	9.3	8.3	11.6	6.84	3.9	5.9	5.7	6.8	12.5	4.7	18.8	26.9	1.8
MnO	0.36	0.29	0.11	0.11	0.1?	0.2	0.1	0.1	-	-	0.19	0.7	nd
MgO	19.1	19.5	49.0	34.7	17.8	14.5	19.5	19.7	40.4	41.1	12.4	10.5	0.4
NiO	0.02	nd	0.41	0.12	nd	nd	nd	nd	-	-	0.25	-	-
CaO	5.8	5.3	0.05	0.89	18.0	18.3	nd	nd	-	-	nd	0.2	39.4
Na_2O	0.08	0.08	0.01	0.17	1.5	1.5	0.2	0.4	-	-	nd	-	nd
K_2O	nd	nd	nd	nd	nd	nd	10.6	10.7	-	-	nd	-	nd
Sum	101.56	100.26	100.88	101.22	98.9	100.3	96.2	96.3	87.8	86.7	96.94	101.8	>98.3
P	0.007	0.004	-	-	-	-	-	-	-	-	-	-	-
Si	5.935	6.049	0.974	3.916	3.980	3.538	5.397	5.437	6.844	7.720	0.031	0.110	0.093
Ti	0.091	0.147	-	0.010	0.005	0.094	0.617	0.606	-	-	0.755	7.048	7.596
Al	3.073	3.311	0.001	0.062	0.147	0.676	2.442	2.492	0.141	0.090	3.729	0.087	0.153
Cr	0.763	0.408	0.001	0.018	0.075	0.128	0.284	0.057	-	-	5.899	0.116	-
Fe^{3+}	-	-	-	-	-	-	-	-	-	-	0.823	1.480	-
Fe^{2+}	1.120	0.995	0.239	0.393	0.238	0.363	0.686	0.818	2.086	0.749	3.071	4.134	0.279
Mn	0.044	0.035	0.002	0.006	0.006	0.012	0.012	0.012	-	-	0.032	0.109	-
Mg	4.101	4.166	1.797	3.547	1.938	1.590	4.183	4.224	12.015	11.677	3.610	2.876	0.110
Ni	0.002	-	0.008	0.006	-	-	-	-	-	-	0.039	-	-
Ca	0.895	0.814	0.001	0.065	1.409	1.442	-	-	-	-	-	0.040	7.824
Na	0.022	0.022	-	0.023	0.212	0.214	0.055	0.112	-	-	-	-	-
K	-	-	-	-	-	-	1.946	1.964	-	-	-	-	-
Sum	16.053	15.951	3.023	8.046	8.010	8.057	15.632	15.722	21.086	20.236	18.000	16.000	16.055
O	24	24	4	12	12	12	22	22	28	28	24	24	24

1,2 interior and edge of garnet; 3 olivine; 4 orthopyroxene; 5 clinopyroxene Al_2O_3 1.4-2.3, Na_2O 1.2-1.8 for eight analyses, some variations in major elements; 6 clinopyroxene, unusual Al-rich area; 7,8 high- and low-Cr micas; 9, 10 high- and low-Fe serpentines; 11 spinel; 12 ilmenite, minor elements vary considerably; 13 perovskite, probably >1% Nb_2O_5. WDS and EDS analyses for 1-8; EDS only for 9-13. For oxides, Fe_2O_3 calculated for integral formulae. Analysts: R.A. Exley and R.L. Hervig. nd not detected

heavy concentrate of crushed kimberlite during the First International Conference on Kimberlites. Both xenoliths display a coarse texture of olivine and orthopyroxene, but the detailed textural relationships of garnet, clinopyroxene, Cr,Al-spinel, and mica are partly obscured by alteration to serpentine. Much of the serpentine is associated with a multitude of small black specks which are tentatively identified as graphite by analogy with microphotographs in Pasteris (1981). Wide ranges of Fe content of serpentine in both samples (Tables I and II) suggest local variation in oxidation state.

Specimen 73-106 is a lherzolite with scattered grains of garnet (~ 1 mm) surrounded by a brown 'kelyphitic' rim rich in K. A 20 μm rim of garnet contains less Cr than the interior (Table I). Small random grains (~ 0.1-0.2 mm) of pleochroic, foxy-red, Cr-poor mica (cf. Delaney *et al.*, 1980) are mostly surrounded by serpentine which does not traverse the mica, while grains of Cr-rich mica (Table I) abut the kelphite rim (fig. 1*a*). Cr-rich spinel of uniform composition occurs as unaltered, often euhedral, grains surrounded by kelyphitic mica. Mg-rich ilmenite grains are rimmed by perovskite (cf. Haggerty, 1973) and surrounded by serpentine which encloses tiny crystals of apatite.

TABLE II. Electron microprobe analyses of 73-109

	1	2	3	4	5	6	7	8	9
P_2O_5	0.04	0.06	0.015	nd	0.06	0.005	nd	-	-
SiO_2	42.6	42.0	40.5	58.6	54.5	41.2	0.12	40.8	37.0
TiO_2	0.008	nd	nd	0.006	nd	0.06	0.09	-	-
Al_2O_3	21.2	22.1	0.005	0.72	3.42	14.0	12.0	0.6	3.9
Cr_2O_3	3.83	3.1	0.011	0.28	1.93	1.01	54.8	-	-
Fe_2O_3	-	-	-	-	-	-	3.4	-	-
FeO	6.85	7.64	7.05	4.47	2.40	2.68	16.0	2.3	11.7
MnO	0.47	0.44	0.09	0.12	0.07	0.02	0.14	-	0.4
MgO	20.7	20.8	53.2	36.6	16.9	26.7	11.2	44.2	36.7
NiO	0.007	nd	0.41	0.095	nd	0.24	0.11	-	-
CaO	5.17	5.10	0.0	0.20	19.4	0.01	0.04	-	-
Na_2O	0.014	nd	nd	0.06	2.47	0.62	nd	-	-
K_2O	nd	nd	nd	nd	nd	9.5	nd	-	-
Sum	100.89	101.24	101.28	101.15	101.15	96.613	97.90	87.9	89.7
P	0.005	0.007	-	-	0.003	0.001	-	-	-
Si	6.019	5.926	0.972	3.961	3.895	5.752	0.025	7.592	7.110
Ti	0.001	-	-	-	-	0.006	0.014	-	-
Al	3.530	3.674	-	0.057	0.288	2.304	2.903	0.132	0.883
Cr	0.428	0.346	-	0.015	0.109	0.111	8.894	-	-
Fe^{3+}	-	-	-	-	-	-	0.526	-	-
Fe^{2+}	0.809	0.902	0.141	0.252	0.144	0.313	2.747	0.358	1.880
Mn	0.056	0.052	0.002	0.007	0.004	0.002	0.025	-	0.065
Mg	4.360	4.375	1.903	3.687	1.601	5.556	3.427	12.260	10.511
Ni	0.001	-	0.008	0.005	-	0.027	0.018	-	-
Ca	0.783	0.771	-	0.015	1.496	0.002	0.009	-	-
Na	0.004	-	-	0.008	0.372	0.168	-	-	-
K	-	-	-	-	-	1.693	-	-	-
Sum	15.996	16.053	3.026	8.007	7.912	15.935	18.000	20.342	20.449
O	24	24	4	12	12	22	24	28	28

1,2 high- and low-Cr limits of garnet; 3 olivine; 4 orthopyroxene; Al_2O_3 and Cr_2O_3 probably vary about 10%; 5 clinopyroxene; 6 mica, also BaO 0.51, Rb_2O 0.013, Cl 0.04; 7 Cr-spinel; 8,9 low- and high-Fe limits of serpentine. Combination of WDS and EDS analyses for 1-7; EDS only for 8,9. Analysts: R.A. Exley and R.L. Hervig. nd not detected.

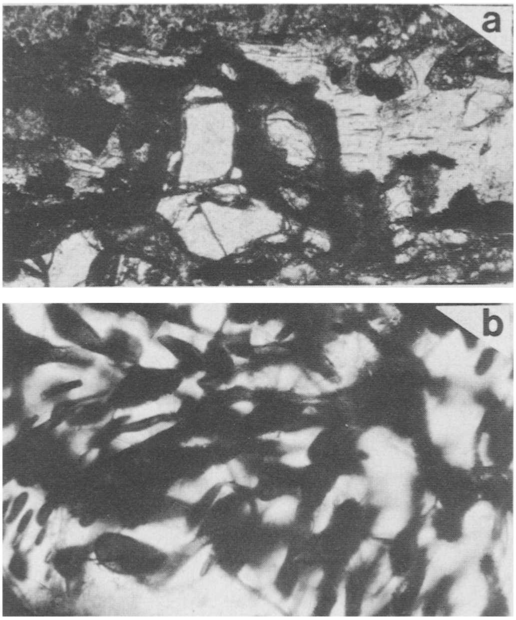

FIG. 1. Photomicrographs. (*a*) 73-106. Partly altered garnet (high relief) with rim of mica (light areas with cleavage traces) enclosing euhedral spinel (black). Fine-grained serpentine occurs at the upper margin. Plane polarized light, 1 mm across. (*b*) 73-109. Spinel inclusions (dark) in garnet (light). Plane polarized light, 0.5 mm across.

The olivine and orthopyroxene grains are traversed by irregular veins of serpentine which appear to have filled brittle fractures. No exsolution lamellae or inclusions were seen in the multiply cleaved grains of orthopyroxene. Some of the small clinopyroxenes (0.1 mm) are associated with garnet and mica, and show variation of Al and Na (Table I). Interpretation of the textures is difficult because of the serpentinization, but the following sequence is suggested: (*a*) prolonged annealing to produce a garnet lherzolite with coarse texture; (*b*) reaction of garnet with other silicates to produce a fine-grained kelyphitic rim, probably of orthopyroxene, clinopyroxene and spinel by analogy with Lock and Dawson (1980): some diffusion of Cr and other elements from the surviving garnet was also involved; (*c*) grain-boundary infiltration of K, volatiles and other elements to produce mica at the expense of orthopyroxene and most of the clinopyroxene; and (*d*) serpentinization associated with formation of graphite and alteration of ilmenite to perovskite. Stages (*b*) and (*c*) may have been partly concurrent. There is no textural evidence that requires derivation of the spinel by exsolution from orthopyroxene, but exsolution of either garnet or spinel or both might have preceded stage (*a*). Because all the minerals are comparatively rich in Ti (Table I), the ilmenite may have existed as primary grains in stage (*a*); however, it might be attributed to stage (*c*) by analogy with the 'primary-metasomatic' assemblages described by Harte and Gurney (1975). Calcite and sulphides were not detected.

Specimen 73-109 is a coarse garnet lherzolite dominated by olivine and orthopyroxene grains up to 3 mm across. The cores of the orthopyroxene grains are filled with long, thin platelets (up to $500 \times 20 \times 2$ μm) of spinel, and the rims are clean (cf. Basu and MacGregor, 1975). In spite of this obvious zoning, the variation in Al and Cr is small (a maximum of 10 % from the mean value; Table II). Garnet grains (0.2–0.5 mm) tend to be associated with clinopyroxene grains (< 0.05 mm). Some garnet grains contain elongated and somewhat rounded inclusions of spinel ranging from a few random individuals to 'sprays' which tend to form curved arrays (fig. 1*b*). This assemblage is quite different from the fingerprint type of intergrowth between spinel and other silicates (Smith and Dawson, 1975), and the closest textural match is with two zoned garnet xenocrysts with inclusions of equant acicular grains of Cr-spinel (Sobolev, 1977, pp. 38 and 41). A single large mica crystal (2 mm) appears to be in textural equilibrium with adjacent silicates as in primary-textured micas (Delaney *et al.*, 1980).

Mineral chemistry. Electron microprobe analyses were obtained with an ARL-EMX-SM instrument using a combination of energy- and wavelength-dispersive techniques. Three figures after the decimal point indicate spectrometer analyses with a detection level not worse than 0.005 wt. % (1σ), two figures indicate spectrometer analyses with a detection level not worse than 0.02 wt. %, and one figure indicates energy-dispersive analyses with a detection level near 0.1 wt. %. Analytical conditions were similar to those in Delaney *et al.* (1980).

Olivine and orthopyroxene are essentially homogeneous; *mg* (atomic Mg/[Mg + Fe]) is higher in 73-109 (ol 0.926, opx 0.936) than in 73-106 (0.876, 0.900), and this is accompanied by lower Ti, Ca, and Na. Clinopyroxene in 73-109 also has high *mg* (0.936), and is a ureyitic diopside in the classification of Stephens and Dawson (1977). The mica in 73-109 falls neatly into the composition range of primary-textured micas (Delaney *et al.*, 1980), and has particularly low Ti (0.06 wt. %).

All minerals of 73-106 are Ti-rich. The garnet is remarkable for its high contents of both Ti and Cr which match quite well into those for garnets in group I harzburgites from Premier (Danchin, 1979), but not particularly well with any of the reference compositions of the twelve classes of garnet recognized by Dawson and Stephens (1975). All the mica is very high in TiO_2 (5.6 %), even for a secondary-textured type (Delaney *et al.*, 1980), and the substantial increase of Cr_2O_3 from 0.5 wt. % in grains not associated with garnet to 2.5 wt. % in ones surrounding garnet indicates the importance of outward diffusion of Cr into mica from garnet. This is confirmed by the existence of a 20 μm rim of lower Cr_2O_3 (3.6 wt. %) around the core (6.7 wt. %) of each corroded garnet. Whereas most analyses of clinopyroxene show moderate Al_2O_3 (1.4-2.3 wt. %) and low TiO_2 (< 0.4 wt. % by EDS analysis) like those of the diopside group (Stephens and Dawson, 1977), one grain in kelyphite (fig. 1*a*) has unusually high Al_2O_3 (7.8 wt. %) and TiO_2 (1.7 wt. %). Although the higher TiO_2 (1.4 wt. %) in the rim than in the core (0.8) of the garnet might be used as evidence for the introduction of Ti from metasomatic vein formation, the possibility that original Ti-zoning remains unaffected should be considered. The TiO_2 content (5 wt. %) of the spinel is rather high (Haggerty, 1975), but the compositions of the ilmenite and secondary perovskite are unexceptional.

Spinel in 73-109 is chemically uniform, and has higher Cr/Al (3.1) than the spinel (1.6) in 73-106, but the *mg* ratios are similar. The garnet in 73-109 is a low-Ca pyrope with nearly uniform composition in each grain irrespective of whether spinel inclusions are present; however, Cr_2O_3 varies slightly from grain to grain (3.8-3.1 wt. %) and FeO varies antipathetically.

A limited data set was given previously (Delaney *et al.*, 1979) for 73-106, and for another garnet lherzolite, 73-105, from Frank Smith. The latter lacks spinel, but is otherwise similar to 73-106, in particular in having garnet zoned from a Cr-rich core to a Cr-poor rim. These two lherzolites are unusual for high Ti, Cr, and Na in the minerals, and for temperatures (next section) very high for lherzolites with coarse textures; they appear to be transitional in these respects to porphyroclastic lherzolites.

Estimates of temperature and pressure. As is common with small nodules, textural information is obfuscated by serpentinization and equilibrium is tested here by using various mineral pairs as thermometers. To mitigate problems with zoned crystals, emphasis is placed on coarse grains with uniform composition, and on the fairly homogeneous interiors of zoned grains.

Temperatures (Table III) for garnet-olivine (O'Neill and Wood, 1979), for two pyroxenes (Wells, 1977), and for two minor-element thermometers calibrated empirically against the Wells thermometer, are in general agreement. A best estimate of 1350 K for the silicates in 73-106 excludes the high value of 1460 K for the lowest Na analysis of clinopyroxene. For 73-109, three temperatures cluster within 10 degrees of 1090 K, while the Wells thermometer for $MgSiO_3$ exchange between ortho- and clinopyroxene is 100 K higher. Perhaps the clinopyroxene did not reach equilibrium with the other three silicates; for the latter a rounded value of 1100 K is suggested.

There is considerable controversy over the application of barometers, but it does not seem profitable to pursue details. The Wood and Banno (1973) orthopyroxene-garnet barometer gives pressure in the range 39 to 47 kb for 73-109 when account is taken of chemical zoning. Similar orthopyroxene compositions in 73-106 suggests a comparable pressure range. The coarse texture of both samples is typical of the textures of many peridotite nodules from S. African kimberlites which Boyd (1973) and other scientists have attributed to prolonged annealing near 1300 K and 40 kb.

Origin of spinel-garnet textures. The intimate relation between the spinel and garnet in 73-109 requires detailed discussion. Simultaneous growth of the two minerals seems to be the most plausible explanation of the texture in fig. 1*b*. Each spinel crystal appears to have grown independently from the other spinel crystals. All faces are either planar or convex, and there are no concave or scalloped indentations that might be indicative of corrosive transformation of spinel to garnet. Neither does the texture appear indicative of exsolution of spinel from garnet, or of transformation of garnet to spinel. The curvature of the arrays argues against expitaxial crystallization. Perhaps the simplest cause of simultaneous crystallization would be simultaneous exsolution of garnet and spinel components from orthopyroxene in the stability field

TABLE III. *Estimated temperatures* (*Kelvin*) *of peridotites*

	73-106	73-109
1. GT-OL	1340	1100
2. OPX-CPX	1350	1200
3. OPX-CPX	1350, 1460	1080
4. OPX-OL	1360	1090

1. O'Neill and Wood (1979): Fe-Mg exchange. 2. Wells (1977): Mg exchange. 3. Hervig and Smith (1980): Na exchange. High and low temperatures correspond respectively to low and high Na in the clinopyroxene. 4. Hervig and Smith (1981): Cr exchange. Revised equation: T (Kelvin) = $5540/(1.86+\ln K)$ where $K = Cr_2O_3(OPX)/Cr_2O_3(OL)$ in wt. %.

of coexisting garnet and spinel. If this is correct, diffusion was sufficient to produce a spinel-free rim in the orthopyroxene, but not sufficient to give a spinel-free core. Absence of garnet inclusions in the orthopyroxene might be used as evidence against simultaneous exsolution of garnet and spinel components, but perhaps the rock had moved out of the range of garnet stability at the end of the exsolution process.

Cr,Al-distribution between garnet and spinel. The model reaction orthopyroxene + spinel = garnet + olivine marks the transition from the spinel-peridotite to the garnet-peridotite facies with increase of pressure. As already noted, MacGregor (1970) showed that this transition occurs at greater pressure in a system with higher Cr/(Cr + Al) as Cr stabilizes the spinel. Wood (1977) preformed experiments to sudy the effect of Cr_2O_3 on the transition, and because of the coupling of Ca and Cr in garnet, he plotted $ln\,K_D(K_D = (Cr/Al)_{gt}/(Cr/Al)_{sp})$ *vs.* X^{gt}_{Ca} for coexisting spinel and garnet in Lesothan lherzolites analyzed by Nixon and Boyd (1973), in order to estimate the effect of non-ideality of garnet on the model reaction. A more complex version of the plot (fig. 2) incorporates data from papers listed in the introduction.

The most obvious conclusion from fig. 2 is that kelyphitic spinels inherit the Cr/Al ratio of the primary garnet, which indicates near isochemical retention of Cr and Al around the garnet rim ($K_D = 1$).

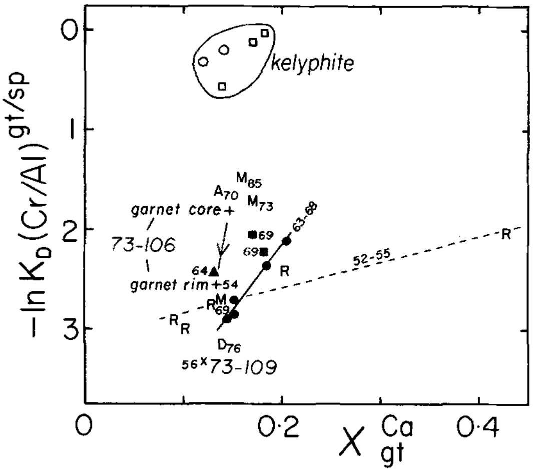

FIG. 2. Relation between ln $K_D(Cr/Al_{gt}/Cr/Al_{sp})$ and mole fraction of Ca in garnet. Symbols: filled circle, Thaba Putsoa, Nixon and Boyd (1973); filled square, Pipe 200, Carswell *et al.* (1979); filled triangle, Kao, MacGregor (1979); R, Mir, Russia, Sobolev (1977); M, Malaita, Solomon Islands, Nixon and Boyd (1979); A, SE Australia, Ferguson *et al.* (1977); D, Dish Hill, California, Shervais *et al.* (1973); open square, Pipe 200, Carswell *et al.* (1979); open circle, Letseng, Lock and Dawson (1980); horizontal and inclined crosses, 73-106 and 73-109, this paper. Small numbers show 100 *mg* of spinel.

Primary-textured spinels and garnets have a strong preference of Cr for the spinel ($K_D < 1$). Factors which control the distribution will be complex, but important variables are pressure, temperature, and compositional factors such as X^{Ca}_{gt} (which correlates positively with X^{Cr}_{gt}) and *mg*.

The five points for Thaba Putsoa, Lesotho (filled circles) involve spinels in which *mg* varies only from 63 to 68, and they appear to define an equilibrium trend (continuous line) already recognized by Wood. The five points for the Mir pipe, Russia (R) involve spinels in which *mg* varies only from 52 to 55, and they also might be attributed to an equilibrium trend, but quite different from the one for Thaba Putsoa. Both the Mir and Thaba Putsoa regions are in stable cratons with similar geotherms of continental type for the granular peridotites. The two specimens for Pipe 200, Lesotho (filled square) are somewhat displaced from the Thaba Putsoa trend, and that for Kao, Lesotho (filled triangle) is considerably displaced in spite of similar *mg* values. Perhaps a reinvestigation is needed to check whether there is textural evidence of lack of equilibrium especially for the Kao specimen. The linear trends at similar K_D values for Mir and Thaba Putsoa indicate an equilibrium distribution corresponding to similar *P*, *T* conditions.

The present spinel-garnet pair 73-109 lies closer to the Thaba Putsoa trend than the Mir trend even though the *mg* value of 56 is closer to the range of 52-5 for the latter. For 73-106, it is expected that the spinel would be in closer relationship to the rim of the garnet than to the core, and indeed the rim is closer to the Thaba Putsoa trend than is the core. It is quite clear that the garnet-spinel relation is different from that found in the typical kelyphites.

Specimens M (Malaita, Solomon Islands), A (SE Australia), and D (Dish Hill, California) in fig. 2 are for higher *T* and lower *P*. Because reduced pressure lowers Cr in spinel, higher values of K_D should ensue, and indeed the Australian specimen and two from Malaita agree with expectation. However, one from Malaita and the Dish Hill specimen do not agree, and perhaps late disequilibrium crystallization of spinel may be responsible.

The recent experimental work of O'Neill (1981) shows that the transition pressure from spinel lherzolite to garnet lherzolite is raised linearly with X^{Cr}_{sp} for a maximum increase of ~ 28 kb for pure Cr-spinel. From the present survey of Cr/Al partitioning, it appears that problems of disequilibrium, either involving kelyphitization of garnet or late crystallization of spinel, must be carefully assessed before this barometer is applied.

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