COMPARATIVE GEOCHEMICAL EVOLUTION OF CRATONIC LITHOSPHERE: SOUTH AFRICA AND SIBERIA

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This paper compares geochemical data (trace elements by proton microprobe) on diamond-inclusion minerals (DI) and the the corresponding phases in heavy-mineral concentrates, from kimberlites in Siberia (SIB) and southern Africa (SA). The SIB data are from Udachnaya, Aikhal, Sytykanskaya and Mir pipes; the SA concentrate data and most of the DI data are from kimberlites on the Kaapvaal craton, but the DI data include a few grains from Botswana. Published Nd model ages on garnets indicate Archean ages for peridotite-suite diamonds in both SIB and SA kimberlites. Comparison of major- and trace-element patterns in diamond-inclusion (DI) garnets and spinels from these two areas shows many similarities, and some important differences.

Garnet DI populations are dominated by subcalcic pyropes in both areas, but calcic (lherzolitic) garnets may be more common in SA. The Nickel Thermometer (Griffin et al, 1989) has been used to estimate temperature (T_{Ni}) for individual garnet grains. T_{Ni} in South African DI garnets ranges from 950-1500 °C; in SIB garnets the range is 800-1500°C, but all DI with T<950°C are from the Mir pipe. The DI garnets from SA and SIB show similar patterns of depletion in Zr, Y, Ga and Ti, and enrichment in Sr, with decreasing Ca/Cr. However, SIB DI garnets have higher median Cr# values, and lower median Mg# values, than DI from South Africa. Chromite is an abundant DI phase in SIB kimberlites, and less common in SA. DI chromites from the two areas show similar ranges in Cr#, Ni and Ga, but those from SIB have lower median MgO and Mg#, and higher Cr/Mg, Fe and Zn. The differences in Mg# of garnet and chromite DI populations between the two areas, and the lower Zn in the SA chromites, would be consistent with a 150-200°C higher average T beneath SA at the time of diamond formation. However, this difference is not apparent in the T_{Ni} values of DI garnets, which show very similar mean and median temperatures for the two cratonic areas. In addition, the well-defined Fe-Zn correlations in the DI chromite populations (Fig. 1) are *en echelon*, rather than continuous with one another as would be expected if only a T difference was involved. It therefore appears that the deeper portions of the cratonic lithosphere beneath SA had lower Cr and higher Mg# than the Siberian mantle, at the time of diamond formation.

Comparison of garnet concentrates from diamondiferous kimberlites also shows several significant differences between SA (Kaapvaal craton) and SIB. Concentrates from both areas contain significant proportions of subcalcic garnets, but moderately subcalcic pyropes (3-5% CaO) appear to be more common in SIB concentrates, relative to extremely subcalcic and lherzolitic garnets. The concentrates show a similar range of T_{Ni}, but the SIB distribution is strongly weighted toward lower T relative to the SA distribution. Other factors being equal, this lower T distribution would imply a greater proportion of material from the graphite stability field in the Siberian pipes. This is not consistent with their high diamond grades; the favored alternate interpretation is that the geotherm at the time of emplacement of kimberlites was lower beneath Siberia than beneath the Kaapvaal craton. The existence of low-T (<950°C) DI garnets in SIB suggests that a similarly low geotherm may have existed in Archean time. The maximum Cr content of concentrate garnets shows a strong correlation with T (and presumably with P) in both sets of concentrates (Fig. 2). However, the SIB garnets show higher Cr (maximum and average values) at any T than those from SA. SIB concentrate garnets also have higher median Cr/Mg and lower median Mg# than those from SA, mirroring the differences seen in the DI garnet populations.

SA concentrate garnets are significantly enriched in Zr, Y and Ga relative to those from SIB. The median Zr and Y contents of calcic garnets (>4% CaO) in SA are 35 and 13 ppm, respectively, compared to 28 ppm Zr and 9 ppm Y for SIB garnets. 30% of such garnets in SIB concentrates have <10 ppm Zr, compared to 12% of SA garnets. The low-Ca garnets in both areas are very depleted in Y (median 2-3 ppm), but those in SA are considerably richer in Zr, with a median value of 24 ppm compared to 14 ppm in SIB. Significant levels (>5ppm) of

Sr, like those seen in DI garnets, are common in the subcalcic garnets of the SIB concentrates, but very rare in the SA concentrates.

Comparison of the DI and concentrate data suggests that the SA lithosphere is lower in Cr and Cr/Mg, and higher in Mg#, than the SIB lithosphere. The SA mantle is thus more refractory in terms of Mg#, but less refractory in terms of Cr#; this is inconsistent with a simple difference in degree of depletion through removal of basic melts. These differences existed at the time of Archean diamond formation, and have persisted since. The SA lithosphere is enriched in Zr and Y relative to the SIB lithosphere, and probably contains a lower proportion of highly depleted harzburgite. These differences in LIL elements and possibly in bulk Ca content were established after diamond formation.

These differences may be related to other significant differences in kimberlite mineralogy between the two cratons. The maximum, and perhaps mean, diamond grades of Siberian kimberlites are reported informally to be higher than those of kimberlites on the Kaapvaal craton. Siberian diamonds from the pipes considered here are typically octahedra with little evidence of resorption, while SA diamonds typically are dodecahedral, and have lost up to 50 % of their mass by resorption. K-richterite and other metasomatic minerals occur in many SA pipes, but apparently are rare in SIB ones. Finally, the garnets of sheared garnet peridotites from SA kimberlites show elevated Fe3+ contents (Luth et al., 1990), suggesting that the melt metasomatism that affected these xenoliths (Griffin et al. 1989b) has involved an increase in the oxygen fugacity of the lithosphere.

We suggest that: (1) Early Archean processes were similar in the SA and SIB lithospheres, leading to depletion in most LIL and HFSE elements, a high proportion of harzburgite relative to lherzolite, and enrichment of very subcalcic garnets in Sr (and LREE). (2) The differences in major-element composition (Cr#, Mg#) were established in very early Archean time, and do not reflect simple differences in degree of depletion; they may reflect original heterogeneity. (3) the SA lithosphere was "refertilized" following diamond formation, by metasomatic processes which have affected the Siberian lithosphere little if at all. (4) Effects of these processes include introduction of Zr, Y and Ca (and probably K and Ti); reduction in the proportion of harzburgite to lherzolite, and stripping of Sr and LREE from subcalcic garnets. (5) The same process may have raised the oxygen fugacity of the SA lithosphere, leading to resorption of diamonds whether in the mantle wall rock, or in later kimberlites which have been buffered to the oxidation state of those wall rocks.

Griffin, W.L., Cousens, D.R., Ryan, C.G., Sie, S.H. and Suter, G.F. 1989a. Contrib. Mineral. Petrol. 103, 199-202.
Griffin, W.L., Smith, D., Boyd, F.R., Cousens, D.R., Ryan, C.G., Sie, S.H. and Suter, G.F. 1989b. Geochim. Cosmochim. Acta 53, 561-567.
Luth, R.W., Virgo, D., Boyd, F.R. and Wood, B.J. 1990. Contrib. Mineral. Petrol. 104, 56-72.

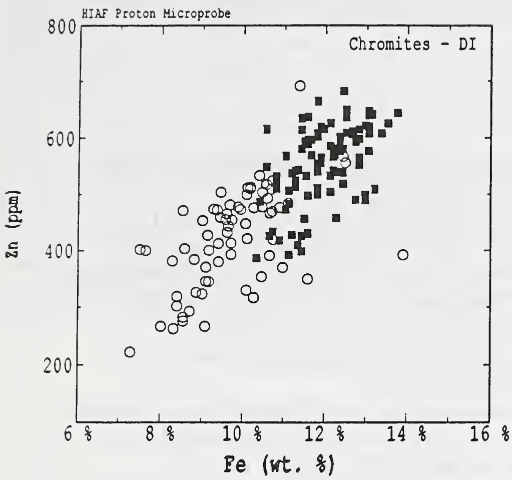
FIGURES (next page)

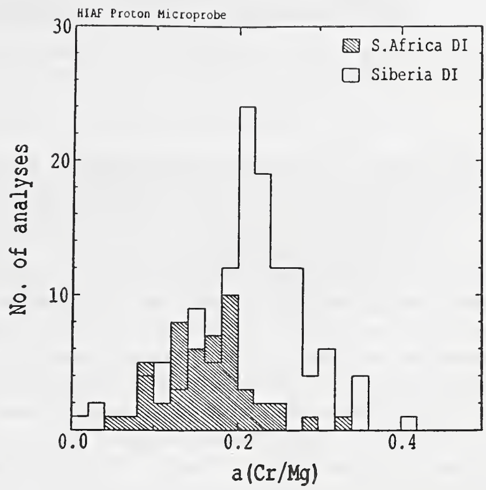
Fig. 1 (top left). Fe-Zn relations in DI chromites. Squares, SIB; circles, SA. The trends toward higher Fe and Zn in each group reflect cooling.

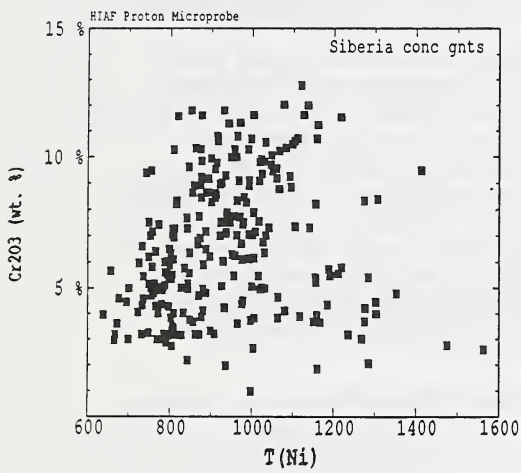
Fig. 2 (top right). Histograms of Cr/Mg for DI garnets. Hatched area: SA; clear, SIB.

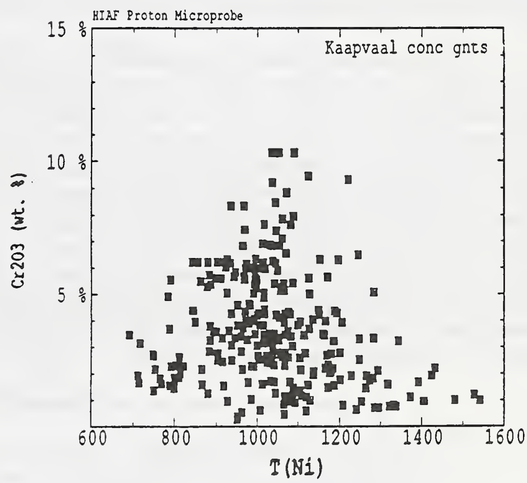
Fig. 3 (middle). Cr-T relations in concentrate garnets from SIB and SA.

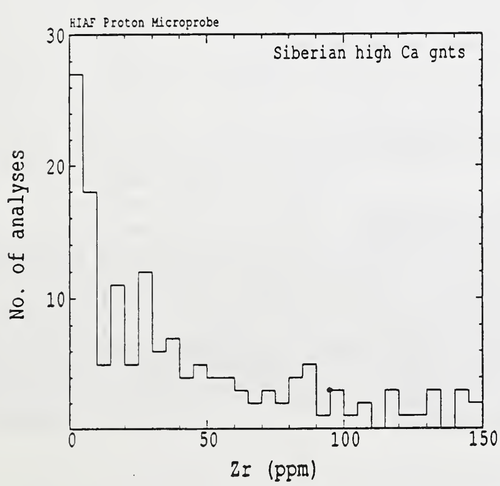
Fig. 4 (bottom). Histograms of Zr content in high-Ca (>4% CaO) concentrate garnets from SIB (n=147) and SA (n=128).

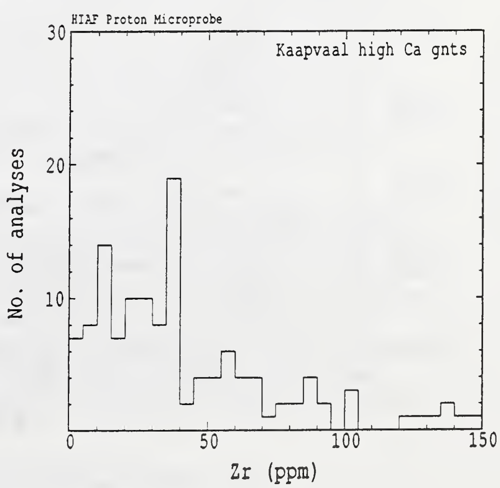

HIAF Proton Microprobe
Chromites - DI
Zn (ppm)
800
600
400
200
6 %
8 %
10 %
12 %
14 %
16 %
Fe (wt. %)


HIAF Proton Microprobe
S.Africa DI
Siberia DI
No. of analyses
30
20
10
0.0
0.2
0.4
a(Cr/Mg)


HIAF Proton Microprobe
Siberia conc gnts
Cr2O3 (wt. %)
15 %
10 %
5 %
600
800
1000
1200
1400
1600
T(Ni)


HIAF Proton Microprobe
Kaapvaal conc gnts
Cr2O3 (wt. %)
15 %
10 %
5 %
600
800
1000
1200
1400
1600
T(Ni)


HIAF Proton Microprobe
Siberian high Ca gnts
No. of analyses
30
20
10
0
50
100
150
Zr (ppm)


HIAF Proton Microprobe
Kaapvaal high Ca gnts
No. of analyses
30
20
10
0
50
100
150
Zr (ppm)