CHROMITE MACROCRYSTS IN KIMBERLITES AND LAMPROITES: GEOCHEMISTRY AND ORIGIN.

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Introduction: Macrocrysts of chrome-spinel (CMs; 0.2-2mm, anhedral to euhedral) are common in many kimberlites and lamproites, and are important as indicator minerals during diamond exploration. However, the use of chromites in exploration is usually based on major-element criteria which may be ambiguous. Analysis of trace elements by proton microprobe can add another level of discrimination, and a program to this effect is in progress at the CSIRO. Here we discuss major- and trace-element data on >1000 chromites from kimberlites and lamproites worldwide, on >170 diamond-inclusion (DI) chromites from South Africa and Siberia, and on >70 garnet-chromite pairs from xenoliths and concentrates. Data for various elements are combined in Figure 1.

Data: CMs from kimberlites show limited ranges in Cr2O3 (45-65%) and Al2O3 (2%-12%; Cr# [Cr/(Cr+Al)] ranges from 0.7 to 0.95. Lamproite CMs show a much greater range to lower Cr and higher Al, with Cr# down to 0.2; there is little overlap in Al2O3 between kimberlite and lamproite CM populations. Mg# [Mg/(Mg+Fe)] ranges mainly from 0.4 to 0.7. CMs from Group 2 kimberlites extend to lower Mg# than those from Group 1 kimberlites, and lamproites contain significant numbers of high-Mg#, low-Cr# spinels. In general there is no correlation between Mg# and Cr#; the low-Cr "tail" in Fig. 1 is defined by a small proportion (<10%) of the sample.

More than 1/3 of the analyzed CMs contain >1% TiO2, and many, especially in Group 2 kimberlites, contain 2-4%. Ti typically shows a broad negative correlation with Al and Mg#, and a weak positive correlation with Cr#, expecially in lamproites. In general, therefore, chromite macrocrysts from kimberlites and lamproites follow the first part of Mitchell's (1987) "Trend 2", rather than the "AMC trend". Ni contents of CMs range from 300-2000 ppm; they show no correlation with Mg# or MgO, but are broadly anticorrelated with Cr. The highest Ni values are found in the low-Cr CM populations in lamproites. Group 2 kimberlites contain two major populations of CMs with Ni contents of ca. 400-700 ppm and 900-1200 ppm, respectively; Group 1 kimberlites have one major population with ca. 600-900 ppm. Zn contents of CMs in kimberlites are mainly in the range 400-900 ppm, with a few higher values. Lamproites, and some Siberian kimberlites, contain many CMs with Zn >1000 ppm; the high-Ni population in lamproites contains 200-500 ppm Zn and shows a negative correlation between Zn and Ni. Ga contents of CMs range from <2-100 ppm, and show a broad positive correlation with Ni.

DI chromites show narrow ranges of Cr# and Mg#, and for most trace elements as well. Siberian DI chromites show significantly lower Mg# and MgO, and higher Zn, than those from South Africa. Ti and Ga contents of DI chromites are typically low , but even lower values of Ga are found in CMs from kimberlites.

Harzburgite chromites typically lie in a very narrow range of Cr# and Mg#, while lherzolite spinels show a wider range of Cr# and a rough negative correlation between Cr# and Mg#. Only four xenolith spinels, all from lherzolites, contain >1000 ppm Ni. 10% of the analyzed xenolith spinels, divided equally between harzburgites and lherzolites, contain >1% TiO2. In general, lherzolite spinels contain less Ni, more Ga and more Zn than harzburgite spinels. The Nickel Thermometer (Griffin et al., 1989) allows calculation of a temperature for each garnet-chromite pair. Fig. 2 shows a good correlation between 1/T and the Zn content of the xenolith spinels, and probably reflects partitioning between chromite and olivine. The correlation between Ni and 1/T is not as good, which suggests bulk-composition effects on the partitioning of Ni.

Discussion:

(1) Origin of macrocryst chromites: Comparison of the CM populations with the data on xenolith spinels provides clues to the origin of chromite macrocrysts. The low-Ti

CMs in Group 1 kimberlites appear to be true xenocrysts, derived mainly from harzburgites. Very low-Ga CMs from these kimberlites may be derived from as garnet-free chromite harzburgites and dunites. Group 2 kimberlites contain two major populations, one of which is equivalent to the xenolith spinels. The minimum Zn content of this population is higher than the equivalent in Group 1 kimberlites, indicating a lower maximum temperature. The other population in Group 2 kimberlites is essentially identical to Mitchell's (1987) "Trend 2", and is considered to be magmatic (phenocrystal) in origin. CM concentrates from some Group 2 kimberlites are dominated by this magmatic population. CMs intermediate between the two major populations in Group 2 kimberlites may reflect reaction of xenocryst spinels with (proto-?)kimberlite magma; this may also be the origin of high-Ti CMs in Group 1 kimberlites. CM concentrates from lamproites typically contain relatively few xenocrystal spinels, and many of these are low-T lherzolite chromites. The major CM population in many lamproites has high Ti, Ni, Cr and lower Mg#. It also follows Trend 2, but at higher Mg#, MgO and Ni, and lower Zn, than the corresponding population in Group 2 kimberlites. It is interpreted as a magmatic population, reflecting a higher temperature of crystallization.

(2) Mantle stratigraphy and origin of host rocks: The general separation of the xenolith spinels with harzburgites at high T and lherzolites at lower T (Fig. 2) might reflect a general stratification of the cratonic lithosphere. Alternatively, it may reflect a general lack of spinel-bearing lherzolites at greater depth. The distribution of T_{Ni} in garnet concentrates from kimberlites strongly suggests that lherzolites and harzburgites are interleaved in the deeper parts of the lithosphere, and that lherzolites are volumetrically dominant.

The Mg and Zn distributions in their respective xenocryst populations suggest that Group 1 kimberlites have sampled the mantle from greater depths, on average, than Group 2 kimberlites. This is consistent with derivation of Group 1 kimberlites from the asthenosphere and Group 2 mainly from the lithosphere. Sr-Nd data suggest that both Group 2 kimberlites and lamproites are derived from enriched lithosphere; the differences in their magmatic CM populations suggest that the major difference between the two rock types is the higher temperature of lamproitic magmas.

(3) Implications for Exploration: The use of "diamond inclusion" compositions to evaluate exploration targets may be misleading, since MgO contents, in particular, will be affected by cooling following diamond formation. Also, many high-grade Group 2 kimberlites are dominated by the magmatic CM population, which should be recognized as a positive indication although it has lower Mg# and Cr# than DI chromites. The low-P limit of the diamond stability field corresponds to ca. 950°C on a cratonic geotherm; reference to Fig. 2 shows that only chromites with <ca.700 ppm Zn, and >ca. 600 ppm Ni, are likely to be derived from the diamond stability field. The Ga content of chromites appears to correlate broadly with degree of depletion; DI spinels and harzburgite spinels typically contain <30 ppm Ga. The proportion of chromites with low Zn and Ga, and high Ni, in a concentrate may serve as a rough guide to the diamond potential of an exploration target.

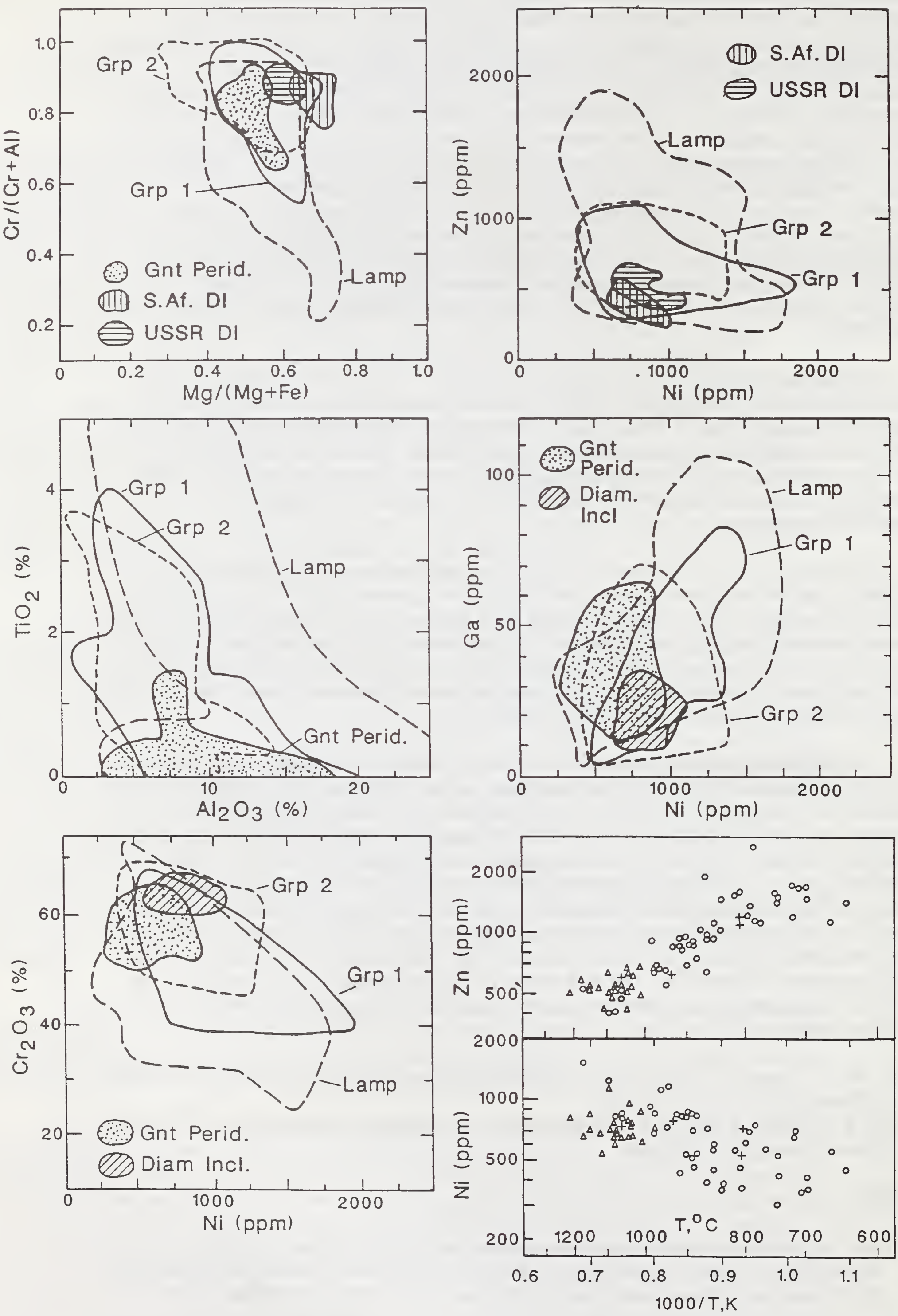
Griffin, W.L., Cousens, D.R., Ryan, C.G., Sie, S.H. and Suter, G.F. 1989. Contrib. Mineral. Petrol. 103, 199-202.

Mitchell, R.H. 1987. Kimberlites: Mineralogy, Geochemistry and Petrology. Plenum Press, New York, 442 pp.

FIGURES (next page)

Fig. 1 a-e. Interelement relations in chromite macrocrysts from Group 1 and 2 kimberlites (Southern Africa) and lamproites (Australia, China, USA), compared with data from diamond-inclusion chromites and chromite-garnet peridotites.

Fig. 2 (lower right). Zn and Ni contents of chromites, plotted against 1/T as determined by nickel thermometry on coexisting chrome-pyrope garnets.


Grp 2
Grp 1
Gnt Perid.
S.Af. DI
USSR DI
Lamp
Cr/(Cr+Al)
Mg/(Mg+Fe)
S.Af. DI
USSR DI
Lamp
Grp 2
Grp 1
Zn (ppm)
Ni (ppm)
Grp 1
Grp 2
Lamp
Gnt Perid.
TiO2 (%)
Al2O3 (%)
Gnt Perid.
Diam. Incl
Lamp
Grp 1
Grp 2
Ga (ppm)
Ni (ppm)
Grp 2
Grp 1
Lamp
Gnt Perid.
Diam Incl.
Cr2O3 (%)
Ni (ppm)
Zn (ppm)
Ni (ppm)
T, °C
1000/T,K