Kimberlite- and lamproite-borne chromite phenocrysts with "diamond-inclusion"-type chemistries

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It is a common experience for diamond explorationists to follow chromites with chemistries identical to chromites included in diamonds (CID) to a typically kimberlitic source rock, only to find that their new discovery contains no diamonds (e.g. Fig. 3e in Gurney and Zweistra, 1995). This leads to the suggestion that CID-type compositions may occur in a non-diamond association within broadly kimberlitic and lamproitic rock types. In this contribution we argue that these "diamond-inclusion" chromites represent an early magmatic phenocryst population which is present in the 0.3 to 1.5 mm size fraction and is a common constituent of kimberlites and lamproites.

Peridotitic chromites that occur as inclusions in diamond have chemistries that are conventionally constrained by the following limits (wt%): 62.0 - 68.0 Cr_2O_3, 10.4 - 16.5 MgO, ≤ 0.6 TiO_2 and < 6.0 Fe_2O_3calc (e.g. Fipke et al., 1995). A survey of representative spinel concentrates from world-wide kimberlites (n = 1220) and lamproites (n = 89) shows that 5.5% of $4.2x10^5$ spinel analyses on grains larger than 0.3 mm meet the CID compositional criteria given above. Some 86% of the CID-type compositions occur in diamondiferous intrusives where they represent 0.1 to 64.5% of the concentrate spinels (mean: 9.1 ± 10.4%), while the remaining 14% of CID's occur in barren intrusives where they make up 0.1 to 56.4% of the concentrate spinels (mean: 4.3 ± 7.0%). These summary statistics indicate that the presence and abundance of CID-type grains can only serve as a crude measure of the presence or absence of diamonds in an exploration target, and can on occasion be completely misleading.

Compositional data for chromites in peridotite xenoliths and chromites included in diamonds are shown on Figure 1. The compositions of chromites in chromite+garnet peridotites are specifically differentiated because they define the maximum Cr_2O_3 content of peridotitic chromite at typical mantle P-T-fO_2 conditions. Inter-element partitioning in chromite+garnet assemblages also allows identification of primary equilibrated chromite compositions, but this is quite difficult for garnet-absent assemblages. In chromite Cr_2O_3-TiO_2 space the data for chromite+garnet assemblages define a sloping envelope (labelled MAXCR in Fig. 1) that is also valid for most of the data from garnet-absent assemblages; a few outliers are thought to represent non-primary chromite compositions. At low TiO_2 the MAXCR envelope is shifted to ~ 2.2 wt% higher Cr_2O_3 to accommodate the data for chromites included in diamond (Fig. 1). The shift may be interpreted as indicating higher pressure or lower temperature (see Brey et al., 1991) or lower fO_2 during chromite encapsulation in diamond, relative to normal mantle P-T-fO_2 conditions. We conclude that the MAXCR envelope delineates the outermost Cr_2O_3-TiO_2 limits of primary chromite compositions in mantle peridotites and that its' position reflects typical mantle P-T-fO_2 relations, while its' slope is determined by spinel stoichiometry. Comments on CID data plotting at Cr_2O_3 > MAXCR are given below.

Our database of representative concentrate spinel compositions shows that 0.3 – 1.5 mm chromites with MgO > 6.0 wt%, TiO_2 < 5.5 wt% and Cr_2O_3 > MAXCR make up 5% or more of the spinels in 52.8% of diamondiferous intrusives and 26.8% of barren intrusives. Mean abundances are 12.2 ± 13.3% in diamondiferous bodies and 7.0 ± 9.8% in barren bodies, but maximum abundances may range up to > 50%. Examples from the Wesselton kimberlite mine and the barren Omega-2

(marginal) kimberlite are shown in Figures 2 and 3. Because these high-Cr_2O_3, low to moderate TiO_2 chromites cannot be derived from mantle peridotite, but are evidently quite common in a variety of high-pressure melts, we interpret them as early magmatic phenocrysts that crystallise from their host, most likely at mantle pressures in excess of 30 kbar.

There is compelling evidence that many high Cr_2O_3, low to moderate TiO_2 chromites should be considered as phenocrysts in kimberlite and lamproite magmas: Fig. 16 in Fipke et al. (1995) shows that such chromites posses Cr_2O_3-TiO_2 chemistries that uniquely distinguish kimberlite and lamproite magma compositions from a variety of other mafic and ultramafic rocks, Griffin et al. (1994) have recognised kimberlitic and lamproitic chromite phenocryst populations based on major- and trace-element chemistry, Shcherbakova (1994) described them in a number of octahedral morphologies with kimberlite-specific surface textures that are readily distinguished from xenolith-borne chromites, and we have argued that those grains with Cr_2O_3 > MAXCR must by default represent chromite phenocrysts. We therefore suggest that the xenolith-borne chromites plotting at Cr_2O_3 > MAXCR in Fig.1 represent grains that have (re-?)equilibrated to early magmatic phenocryst compositions and venture that re-equilibration may also explain the ultra-high Cr_2O_3 composition of grain BM-7 which occurs as an (exposed?) intergrowth with diamond from Mir (Sobolev et al., 1971). The five other ultra-high Cr_2O_3 DIC grains appear to be genuine armoured inclusions in diamonds from Mir (AC-75 of Sobolev et al., 1976) and De Beers Pool (unpublished data, but see Phillips and Harris, 1995) and most likely imply diamond growth within reduced, high-pressure kimberlite-like magma compositions. Their slightly elevated TiO_2 contents are significant in this regard.

In conclusion it is noted that the compositions of 0.3 to 1.5 mm sized kimberlite- or lamproite-borne chromite phenocrysts are not restricted to Cr_2O_3 > MAXCR, but extend to ~ 15 wt% lower Cr_2O_3 at any given TiO_2 content. They therefore overlap completely with CID-type compositions and hence provide a convenient explanation for the occurrence of "diamond-inclusion"-type chromites in barren kimberlites and lamproites (e.g. Fig. 3).

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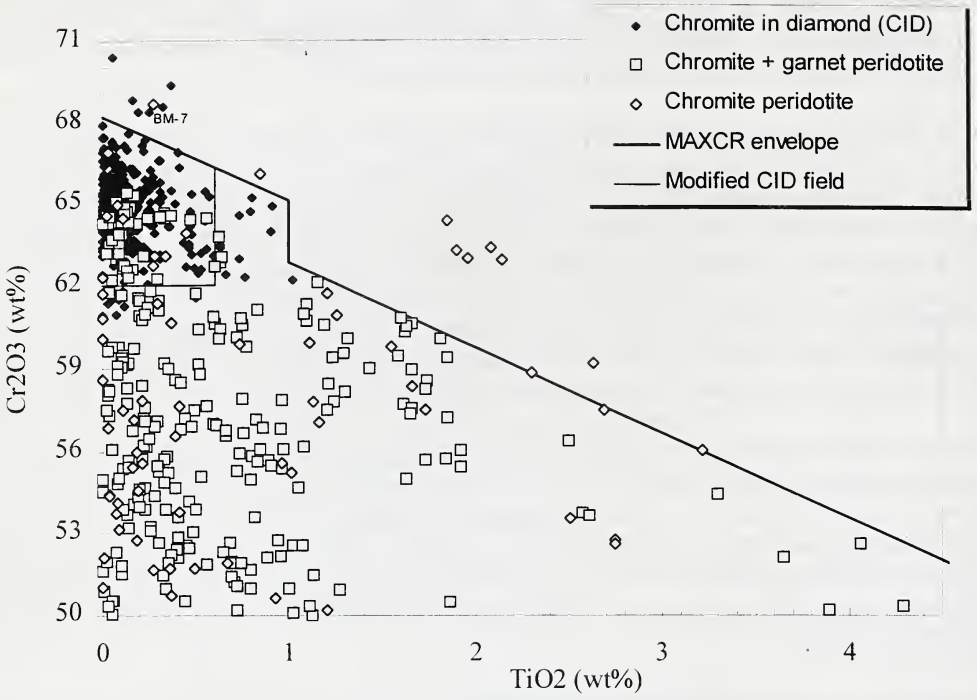
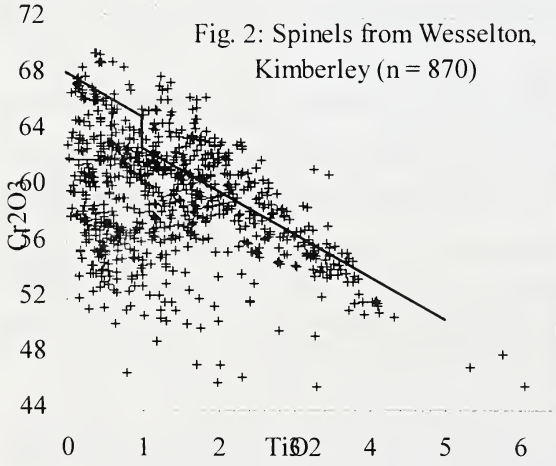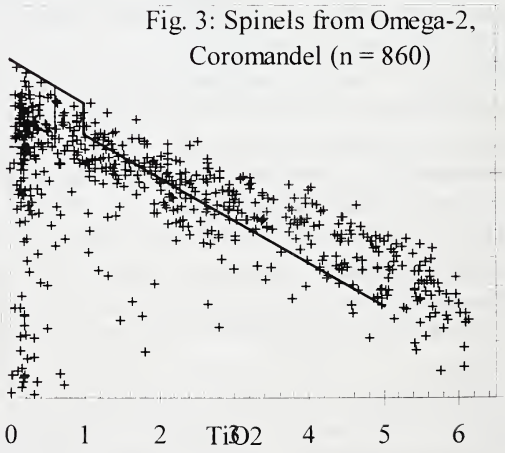
Figure 1: Cr_2O_3-TiO_2 chemistries of chromites in peridotites and chromites included in diamonds. Spinel-garnet phase relations prescribe that all primary chromites in peridotites plot on, or to lower Cr_2O_3 content than, the MAXCR envelope (see text).