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## A high-chromium corundum (ruby) inclusion in diamond from the São Luiz alluvial mine, Brazil

DIAMONDS from the São Luiz alluvial deposit, Mato-Grosso state, Brazil, contain a varied assemblage of inclusions with a mineralogy and geochemistry indicative of formation over a wide range of mantle depths. Two unusual groups of inclusions have been recognised (Wilding *et al.*, 1991; Harte, 1992; Harte and Harris, 1993). The first is an eclogitic suite, with assemblages dominated by both normal- and high-silica garnet with associated clinopyroxene. These are thought to represent samples of mantle material with a range of depth of origin down to approximately 400km. The second suite contains inclusions of ferropicrinite–magnesiowustite solid solution compositions indicative of lower mantle conditions (> 650km) (Ringwood, 1982; Scott-Smith *et al.*, 1984).

As part of a study of the inclusion suite in diamonds from São Luiz, a highly chromian corundum (containing over 8 wt. % Cr<sub>2</sub>O<sub>3</sub>) has been recovered. Corundum is a common accessory mineral in eclogite–grosopydite mantle xenoliths (Dawson and Carswell, 1990), and is stable over a wide range of mantle conditions (Gasparik, 1984; Harley and Carswell, 1990). Kornprobst *et al.*, (1990) described corundum in clinopyroxene–garnet peraluminous eclogitic pyroxenites from the Beni Bousera ultramafic massif, Morocco. Although rare, corundum and corundum xenoliths (Mazzone and Haggerty, 1989) which appear to be related to alkemites, may contain up to 75%

corundum by mode. The only other corundum inclusion so far found, from a cut diamond of unknown origin (Meyer and Gübelin, 1981), was red and contained 1.30 wt. % Cr<sub>2</sub>O<sub>3</sub> (see Table 1), and was assigned to the eclogite suite of inclusions because of the association of corundum in eclogite and grosopydite xenoliths.

The São Luiz corundum inclusion comes from a Type II diamond (one which contains no nitrogen, normally a common atomic component in diamond) with a variable  $\delta^{13}\text{C}$  (–11.56 to –15.21 against the PDB reference). The inclusion is red, subhedral, approximately 100  $\mu\text{m}$  long and chemically homogeneous. Analyses were performed on a Cameca Camebax Microbeam Electron Microprobe instrument at the Department of Geology and Geophysics, University of Edinburgh. Standards used are a selection of metals, silicates and natural oxides and corrections for matrix effects are made using an on-line  $\Phi(\rho z)$  correction program. Analyses were performed for the elements Si, Ti, Al, Cr, Fe, Mn, Mg, Ca, Ni, Na and K at an accelerating voltage of 20 kV and a beam current of approximately 20 nA. An average analysis ( $n=8$ ) is given in Table 1, along with several corundum and chrome-rich corundum (ruby) analyses from the literature. Corundum is a trigonal oxide, typically containing in excess of 97 wt. % Al<sub>2</sub>O<sub>3</sub>. Chrome-bearing corundum is known as ruby, while Ti- and Fe-bearing varieties are referred to

TABLE 1. Corundum analyses

	1 (av. n = 8)	(st. dev)	2	3	4	5
SiO <sub>2</sub>	0.58	(0.02)	0.29	n.d.	n.d.	0.16
TiO <sub>2</sub>	0.10	(0.01)	0.09	0.18	0.21	0.32
Al <sub>2</sub> O <sub>3</sub>	90.37	(0.20)	97.40	98.98	99.37	100.0
Cr <sub>2</sub> O <sub>3</sub>	8.58	(0.13)	1.30	0.25	0.09	0.05
FeO*	0.28	(0.01)	0.22	0.59	0.67	0.66
MnO	0.04	(0.01)	0.02	n.d.	n.d.	n.d.
MgO	0.40	(0.01)	0.13	0.10	0.10	0.20
CaO	0.01	(0.00)	0.02	n.d.	n.d.	n.d.
Na <sub>2</sub> O	0.01	(0.00)	0.04	n.d.	n.d.	n.d.
K <sub>2</sub> O	n.d.	-	0.00	n.d.	n.d.	n.d.
Total	100.39	-	99.50	100.09	100.44	101.4

FeO\* All Fe as FeO.  
tr Trace.  
n.d. Not detected

1. São Luiz corundum inclusion (average analysis, n = 8).
2. Ruby inclusion, cut diamond of unknown origin (Meyer and Gübelin, 1981).
3. Corundum from a corgaspinite xenolith, (corundum + garnet + spinel), Jagersfontein (Mazzone and Haggerty, 1989).
4. Corundum from a corganite xenolith (corundum + garnet), Jagersfontein (Mazzone and Haggerty, 1989).
5. Corundum from a kyanite eclogite, Roberts Victor mine (Hatton, 1978).

as sapphire. Most corundum analyses contain less than 1 wt. % Cr<sub>2</sub>O<sub>3</sub>, less than 2 wt. % FeO and less than 0.5 wt. % TiO<sub>2</sub>. The Al<sub>2</sub>O<sub>3</sub> content of the São Luiz corundum is low (90.08–90.71 wt. %, and Cr<sub>2</sub>O<sub>3</sub> exceedingly high. The Cr<sub>2</sub>O<sub>3</sub> content of the São Luiz ruby is more than four times higher than the most Cr-rich corundum previously recorded from the mantle (Meyer and Gübelin, 1981—Table 1). Corundum from the Beni Bousera ultramafic massif has low Cr<sub>2</sub>O<sub>3</sub> content (0.16 wt. %) typical of corundum in eclogitic xenoliths (Dawson and Carswell, 1990), and the Cr<sub>2</sub>O<sub>3</sub> contents of the unusual corganite–corgaspinite xenoliths are likewise low (<0.4 wt. %).

The most obvious known parageneses for the São Luiz corundum inclusion are eclogite–grosopydite (as noted by Meyer and Gübelin, 1987) or corganite–corgaspinite, but neither of these parageneses are normally Cr-rich. Thus the São Luiz inclusion was derived from an assemblage with an unusual bulk composition, and the nature of the protolith is obscure. Most eclogite and grosopydite xenoliths from kimberlites appear to have been lithosphere-resident before eruption, although deeper-seated eclogitic parageneses have

been recorded both for xenoliths (Haggerty and Sautter, 1990) and for diamond inclusions (Wilding *et al.*, 1991). The depleted  $\delta C^{13}$  values (–11.56 to –15.21, rather than normal mantle values of approximately –6) are also typical of an eclogite diamond paragenesis. Dienes *et al.*, 1991, have shown, however, that diamonds with depleted  $\delta C^{13}$  are present in both the lithosphere and asthenosphere, so, on the basis of carbon isotopes it is uncertain to which of these mantle zones the São Luiz ruby inclusion belongs.

Gasparik (1984) suggested that phase relations involving garnet + clinopyroxene + corundum will be similar to those involving garnet + clinopyroxene + kyanite. While crustal kyanite rarely contains more than 0.3 wt. % Cr<sub>2</sub>O<sub>3</sub>, kyanite crystals in mantle/ultramafic xenoliths have been recorded which contain up to 12.86 wt. % Cr<sub>2</sub>O<sub>3</sub>, (Sobolev *et al.*, 1968). In addition, it has been demonstrated experimentally that the solubility of Cr<sub>2</sub>O<sub>5</sub> in kyanite increases with pressure (Shiraki, 1978 and references therein). The high Cr content of the São Luiz corundum relative to corundum from eclogitic xenoliths may reflect, therefore, formation at sub-lithospheric

depths, analogous to increased Cr-partitioning in kyanite with pressure. A sub-lithospheric origin for the São Luiz corundum would be consistent with the interpreted depth of origin of other inclusions from this source, but a more precise depth value must await the discovery of a biminerale assemblage containing corundum.

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## A high-precision crystal structure refinement of daqingshanite-(Ce) from the Nkombwa Hill carbonatite, Zambia

DAQINGSHANITE-(Ce) was only recently recognized as a new mineral species, although it is a common mineral at several major rare earth element (*REE*) deposits (Chao and Baker, 1979; Horvath and Gault, 1990; Ren *et al.*, 1983). Its occurrence at the Nkombwa Hill carbonatite was recently described in this journal (Appleton *et al.*, 1992), and that work provided several new mineralogical data for the phase.

The crystal structure of daqingshanite-(Ce) was described by Ximen and Peng (1985) using Bayan Obo material. The crystal structure study, however, lacked precision and yielded a large residual value ( $R = 7.9\%$ ), and thus structural details are lacking. This fact, coupled with the similarity to the huntite atomic arrangement despite the non-parallel formulae and different space groups, invited refinement of the daqingshanite-(Ce) atomic arrangement and comparison to that of huntite. This work prefers a high-precision structure study of daqingshanite-(Ce) and elucidates the huntite-daqingshanite structure relationship.

### Experimental

The procedures for X-ray data collection and structure refinement are given in Ni *et al.* (1993);

TABLE 1. Crystal data and results of Daqingshanite-(Ce) structure refinement

Dimensions	0.12 × 0.13 × 0.14 mm
Cell Parameters ( <i>R3m</i> )	
<i>a</i> (Å)	10.073(10)
<i>c</i>	9.234(5)
Theta limits	0–30°
Scan time (seconds)	≤ 50
Data collected	1664, ± <i>h</i> , ± <i>k</i> , + <i>l</i>
<i>R</i> <sub>merge</sub> (%)	3.1
# unique data	321
# data > 3 σ <sub><i>I</i></sub>	276
<i>R</i> (%)	1.7
<i>R</i> <sub>w</sub> (%)	2.0
Peaks on difference map (e/Å <sup>3</sup> ), (+, -)	1.08, 1.76