

Use of Indicator Minerals in Diamond Exploration: a Comparison between Barren and Fertile Kimberlites in Angola

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INTRODUCTION.

Mining companies have destined many resources in the characterization of kimberlitic deposits, in order to optimize the exploration stage and quickly discriminate between barren and fertile kimberlites. Compositions of some indicator minerals, such as Mg-ilmenite, chromite, garnet and diopside, are assumed to be strongly related to the presence of diamonds in kimberlites.

However, a recent publication by Robles-Cruz et al. (2008) states the presence of a secondary Mg-ilmenite, replacing an early intercumulus Fe-rich ilmenite in the Catoca diamondiferous kimberlite (Angola). As a result, routine chemical analyses on mineral concentrates of ilmenite do not seem to be suitable for determining the diamond grades in this pipe, unless textural observations are considered.

Therefore, the aim of our research is to evaluate the effectiveness of the geochemical analyses of indicator minerals in diamond exploration, focusing on the textural populations observed in thin section.

METHODS.

More than 50 samples from fertile and barren kimberlites were studied in thin and polished section, by using petrographic microscope in transmitted and reflected light. Different textural populations were lately characterised by SEM-EDS and the chemical composition of the main indicator minerals has been determined by EMPA.

GEOLOGICAL SETTING.

Four kimberlites were sampled, two from the Lunda province (NW Angola), and two from Bié (centre Angola). As it occurs in other nearby kimberlites, the

emplacement of these four pipes is controlled by the Lucapa corridor, an extensional tectonic structure which crosses the country from NE (Lundas) to SW (Namibe), for more than 1100km (Egorov et al., 2007). The age of the emplacement is assumed to be Cretaceous, as it is strongly related to the other already dated kimberlitic eruptions of the area (Robles-Cruz et al, 2010).

TEXTURES AND GEOCHEMISTRY OF THE INDICATOR MINERALS.

Chromite.

Four types of chromite were found:

- *Chromite as olivine inclusions:* small euhedral crystals (<30µm) were observed in completely serpentinized xenocrysts of olivine.
- *Atoll chromite:* zoned spinels have a core composed of euhedral chromite. An ulvöspinel-magnetite-titanite rim, 5 µm thick, was found in the outer part. An intermediate ring is commonly occupied by serpentine or calcite.
- *Fine grained chromite in xenoliths:* anhedral small crystals appear both in eclogitic and MARID xenoliths. In some cases they might have been previous chromites which have undergone strong alteration.
- *Euhedral chromite in MARID xenoliths*

Generally chromite from fertile pipes has low TiO₂ and high Cr₂O₃ content. In addition, the composition of the chromite of the groundmass is always far from that found in spinel grains included in diamond, whereas the chromite in xenoliths usually presents compositions close to it (Fipke, 1991).

Some zoning was also observed in chromite grains, and 2 trends were defined from the core to the boundaries:

a. TiO₂ and Fe³⁺ enrichment with simultaneous Cr₂O₃ decrease in the atoll chromite (similar to Roeder et al, 2008).

b. Fe³⁺ enrichment with Cr₂O₃ decrease at constant TiO₂, typical of the chromite in olivine.

Ilmenite.

Four different textural populations of ilmenite were characterized:

- *Anhedral ilmenite xenocrysts:* although their size can range from 50 to 600 µm, they are all homogeneous in composition. Only some grains present replacements by Nb-rutile.
- *Ilmenite with ulvöspinel exsolutions*
- *Ilmenite exsolutions in ulvöspinel*
- *Ilmenite cumulates:* they show evidences of equilibrium between the grains, which can be replaced by rutile or hematite along grain boundaries.

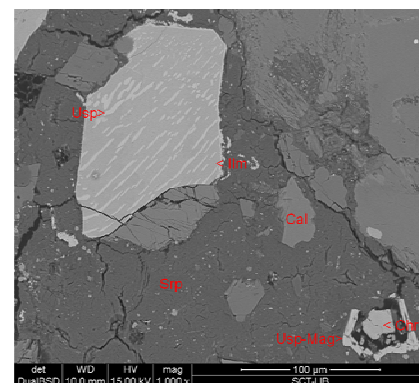


fig 1. Ilmenite xenocryst with ulvöspinel exsolutions and an atoll spinel, in a serpentinized groundmass (usp= ulvöspinel, mag= magnetite, srp = serpentine, ilm= ilmenite, cal = calcite, chr = chromite).

Most of the ilmenite grains present a high Mg content, thus they fit in the "kimberlitic" ilmenite field in the MgO-TiO₂ diagram (Wyatt, 2004). However, ilmenite with ulvöspinel exsolutions systematically falls out of this field. When represented in the Fe₂O₃-MgO

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diagram (Gurney & Zweistra, 1995), the ilmenite grains do not reflect at all the preservation grade of the diamonds, since the diamondiferous kimberlites usually plot in low grade preservation. Similar results were published by Robles-Cruz et al. (2008).

Garnet.

Garnet can appear both as a xenocryst and inside a xenolith, usually as porphyroblast in amphibolites or schists. Locally they also occur in eclogite and garnet peridotite xenoliths and, therefore, can give more information on the composition and characteristics of the lower mantle.

Unlikely to that from the Catoca pipe, garnet is usually very poor in Cr₂O₃ (<1 wt%) and has a wide range of CaO content (1.23-14 wt%). However, lack of ilmenitic and harzburgitic garnets could be explained by scarce sampling.

Cr-rich diopside.

Due to the high alteration degree of these pipes, few diopside grains were preserved. However, 3 different textural populations could be distinguished:

- *Clinopyroxene in xenoliths*: it has a prismatic habit and it is found commonly with garnet in deep xenoliths.
- *Groundmass diopside*: it has a grain size ranging from 20 to 100 µm and it is commonly altered along grain boundaries.
- *Groundmass skeletal diopside*

Two geochemical types of clinopyroxene were distinguished: those with Cr₂O₃ >1 wt%, interpreted as xenocrysts of a garnet peridotite; and those with lower values, of eclogitic origin.

Perovskite.

Only some small (<40µm) perovskite grains were found in our samples. They form euhedral pseudocubic crystals, replaced by anatase.

All the analysed grains are kimberlitic perovskite *sensu strictu*, with low REE, Sr, Nb and Na contents.

DISCUSSION.

Next conditions are essential for a kimberlite to be diamondiferous:

1. The sampled mantle is fertile (inside

the diamond stability field and with an available C source);

2. The diamond can be preserved, by the absence of prolonged oxidising processes at high temperature during - and lately to- the emplacement of the kimberlite; and a fast ascent rates towards the surface.

Geothermobarometric calculations were carried out using the single-Cpx thermobarometer for garnet peridotites proposed by Nimis & Taylor (2000). They made it possible to corroborate that the basement of Lunda is inside the diamond stability field. The results also show a low heat flow (40mW/m²), which is positive for the diamond preservation (Gurney et al, 1979).

A second argument in favour of the presence of diamonds in the mantle beneath Angola is the composition of some chromite grains from xenoliths, which show compositions close to those found as inclusions in diamond. Nevertheless, the presence of a Fe³⁺-rich ilmenite should not be considered as a solid argument to reject the exploitation of a kimberlite, since it has been found in diamondiferous pipes.

However, zoning and textural features of the groundmass chromite show that all the kimberlites studied were affected to a greater or lesser degree by oxidising processes. The Fe³⁺ enrichment trend observed in this spinel and the presence of antigorite (high temperature serpentine), replacing the original groundmass, would indicate an environment which could facilitate the destruction of the diamonds, especially those that were initially in the groundmass.

Finally, the wide range of compositions observed in chromite, pyroxene and ilmenite grains in a single kimberlite suggests it has sampled indeed a heterogeneous mantle. This heterogeneity might explain the duality between barren and diamondiferous kimberlites in the Lundas and Bié provinces, related to the presence or absence of a carbon source at depth.

CONCLUSION.

Although commonly the geochemical composition of the indicator minerals is used independently to their textural features, in this study this criterion is only valid for Cr-diopside. Contrarily, the other indicator minerals analysed show compositional variations according to

the different textural types observed. As a result, if these are not taken into account, it might lead to a misinterpretation of the geochemical data, which would prevent the correct evaluation of the diamond potential of the pipes. Finally, mineral textures have also given significant information about the kimberlite emplacement processes and the diamond grade of these pipes.

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