Diamonds from the Santo Antônio River (Delfinópolis, Minas Gerais): probable relationship with the Canastra-3 Kimberlite

<http://dx.doi.org/10.1590/0370-44672018730051>

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Abstract

The study identifies the Canastra-3 Kimberlite magnetic anomaly as the likely primary source of the alluvial diamonds recovered by “garimpeiros” in the Santo Antônio River basin (Delfinópolis, southwestern Minas Gerais). This conclusion is based on cumulative geophysical, hydrographic, metallogenical and mineral geochemistry evidences. The study area is located within fertile ground in the border of the São Francisco craton, close to other diamond primary sources and secondary deposits. This kimberlitic target is the only known in the Santo Antônio River basin. In addition, the known mineralized gravels of this river, worked in the past by “garimpeiros”, have evidence of a short transport (angular pebbles and blocks), further evidence of a nearby source. The original data collected in the “Minas Gerais Aerogeophysical Survey Program” was processed and analyzed with the Euler Deconvolution method, implemented in software Oasis Montaj. With the exception of the Canastra-3 body anomaly, all others in the study were classified as non-kimberlitic. Recent sampling work on the weathered top of the Canastra-3 Kimberlite recovered indicator minerals, notably a high proportion of pyrope garnets of the G-10 type, which is unusual among the kimberlites of the region.

Keywords: diamond, Santo Antônio River, Canastra-3 Kimberlite, geophysical prospection.

1. Introduction

Minas Gerais and its neighboring areas are home to some diamond provinces with geographic, mineralogical and geotectonic affinities. These provinces encompass tens of thousands of square kilometers. The

Serra da Canastra diamond province is the focus of this study, and stands out as the first in Minas Gerais where a direct link has been identified between alluvial diamond deposits and their primary source – the Canastra-1

Kimberlite in the Vargem Bonita area, in the headwaters of the São Francisco River. The study attempts to establish a similar dependence link between the secondary diamond deposits located on alluvial terraces in the Santo Antônio

River, near Delfinópolis town, with some magnetic anomalies recognized upstream from them.

The Santo Antônio River basin has a very restricted extent, which facilitated a study with this objective. The field characterization of these magnetic anomalies and chemical mineral analyses of Cr-pyrope garnets sampled

at the location of the Canastra-3 magnetic anomaly are used to reinforce the hypotheses that it is likely of kimberlitic nature and source of the diamonds found in the Santo Antônio River terraces. Furthermore, in situ research and new mineralogical studies on other indicator minerals are being conducted to support these hypotheses.

This article represents a continuation of the geological research on kimberlites in the Canastra Range region (Chaves *et al.* 2008a,b), as well as mineralogical studies by electron microprobe on the indicator minerals present in these intrusions, as part of a Masters Dissertation of one of the authors (Andrade, 2012).

2. Location and geological setting

The Santo Antônio River basin is located at the southern portion of the Canastra Mountain Range, southwest of Minas Gerais State and to the north of Delfinópolis small town (Figure 1), with

springs in this range directed to Grande River (Peixoto's Dam). Although a large portion of the diamond province shows a drainage pattern converging with the São Francisco basin, in this area the

ivers flow to the Grande River basin. The two major streams that constitute the headwaters of the basin here studied have their own names: Babilônia and Das Posses creeks.

Figure 1 - Geological setting of Serra da Canastra Diamond Province showing the Santo Antônio River and the Canastra-3 Kimberlite location in the central portion of the map (the Canastra-1 Kimberlite position also is showed) focused on the present study (modified from Heineck *et al.*, 2003).

Heineck *et al.* (2003) identified the oldest rocks of this region as belonging to the Pium-hí Group, a metavolcanic and metasedimentary sequence of Archean age. Mesoproterozoic (?) quartzites and schists of the Canastra Group sustain the mountain range; these two units are thrust faults covered by the Bambuí Group pelites and carbonates, of Neoproterozoic age (Figure 1). The Araxá Group, also of uncertain age, is represented by a thick package of schist rocks, outcropping south of the Canastra Group, and constitutes the bedrock of the studied alluvial diamond deposits. The tectonic evolution of the Neoproterozoic Brasília Fold Belt in this region has been reviewed by Pimentel *et*

al. (2011).

The geological framework is complemented by Mesozoic sedimentary rocks from the Paraná Basin, to the southeast, and chronologically correlated rocks from the Sanfranciscana basin to the northeast. Several kimberlite intrusions occur mainly along the spine of the Canastra Range, cutting quartzites of the Canastra Group. Canastra-1 Kimberlite is the only dated rock body in the region, with a Lower Cretaceous age (120 ± 10 Ma, K/Ar in flogopite), according to Pereira and Fuck (2005).

The geotectonic setting of the region remains the subject of intense controversy. The classic southern boundary attributed to the San Francisco Craton is

about 50-60 km to the east, where the Archean basement (Pium-hí Group) and Upper Proterozoic Bambuí Group outcrop (Figure 1). Such configuration would make the Canastra region unpromising in terms of potential to contain fertile diamond-bearing intrusions. However, Pires (1984) argued that the actual cratonic boundary would be farther to the west, and thus the Lower Neoproterozoic metasedimentary cover (Canastra, Ibiá and Araxá groups) would not have affected the large underlying faults, which would be the ducts of kimberlitic magmatism. The reactivation of such faults during the Mesozoic could have facilitated the emplacement of the intrusions.

3. Diamond alluvial deposits and possible primary sources

Diamond-bearing gravels in alluvial terraces are known in the Santo Antônio River since the beginning of the 1960's, being intermittently mined by panhandling until the late nineties. The singularity of the basin, which cuts the Canastra Quartzite, has provided

few trapping points on the current bed, which have not been mined. Thus, only the river terraces have been worked on several localities of its lower course (Figure 2), raised from 8 to 10 meters above the current channel. Some brief previous references about these deposits

are available in Barbosa *et al.* (1970); Bardet (1977); Fonseca *et al.* (1979); and Chaves *et al.* (2008a,b). The thickness of the alluvial sediments varies from a few decimeters to 1 meter, composed mainly by angular pebbles and blocks of quartz and quartzite.

Figure 2 - Main magnetic anomalies – analytical signal – from Santo Antônio River basin, north of Delfinópolis town (treated and interpreted from CODEMIG, 2005-2006; Area 7).

Since the early 2000s, the State of Minas Gerais has been surveyed by the Minas Gerais Development Company (CODEMIG) in an aerogeophysical program. The Canastra region was included in the "Area 7", mapped on a 1:100,000 scale with flight spacing of 400 m (CODEMIG, 2005-2006), where several kimberlite intrusions

are described. Potentially kimberlitic anomalies can be described by the dipole model (Telford *et al.*, 1990), which represents a small three dimensional structure containing anomalous concentrations of magnetic materials and varying in section from rod-like to spherical. Keating (1995) and Keating and Sailhac (2004) also describe a

model applied to identify kimberlitic bodies, using a vertical cylinder to observe factors that influence the shape of the anomalies: magnetic susceptibility contrast, the solid depth and dimensions and magnetic declination.

The most representative magnetic anomalies of the basin were initially divided into two groups: extensive linear

(Figure 2, indicated with dashed lines - A) and point circular (Figure 2, indicated with arrows - B). The first ones correspond to the tops of the mountain alignments, where the development of a thick ferruginous laterite crust was observed in field works. After the treatment of these anomalies using the "Euler Deconvolution" modern technique (Thompson, 1982; Durrheim and Cooper, 1998), they disappear through a cut in cross section at 50 m depth, evidencing that the crusts have smaller thicknesses than this one.

In short, the Euler Deconvolution makes use of the amplitudes of the analytical signal in the aerogeophysical surveys to derive the horizontal coordinates (x,y) and to estimate the depth of the source through the vertical coordinate (z) of maxim amplitude. The software ARCGIS is used to trace N-S and E-W profiles over each circular anomaly (Figures 3 and 4). These pro-

files are exported to software OASIS MONTAJ used to assign the magnetic values to each point of the profiles, that are exported to the free access software EULER 1.0 developed by the Witwatersrand University (South African Republic). This technique estimates the depth of the magnetic anomalies through the minimum square inversion of the magnetic values and user-defined structural indexes.

Three point circular anomalies were checked in the field (Figure 2 - B1, B2 and B3), however in none of these were there fresh outcrops. The anomaly B3 corresponds to the kimberlite body known as "Canastra-3", discovered and named by the south African SOPEMI-De Beers mining company in 1970s6 (Geologist Luigi Giglio, verbal communication, 2008). The treatments of these structures by "Euler Deconvolution" showed that the designated B1 and B2, when cut to a depth of 50 m,

no longer show the magnetic anomaly. Due to their topographical positions, on transversally fractured mountain spines, they are assumed to represent ferruginous talus deposits supplied in part from laterite erosion.

Furthermore, in the anomaly related to the Canastra-3 Kimberlite (Figure 2 - B3), treated in the same way, the greater depth of the structure was demonstrated. In the case of a pipe that is a subvertical linear source, it originates a field that varies with the inverse of the magnetic field. The maximum depth of 500 m in the described software presented a development in subsurface that defined, through cuts at different depths, a vertical cone-shaped body very typical of kimberlitic intrusions (e.g., Mitchell, 1986; Jaques, 1998). In Figures 3 and 4, the two transversal sections (E-W and N-S) performed by means of the 2D anomaly and their subsurface expressions are represented.

Figure 3 - E-W "Euler Deconvolution" final profile processed on Canastra-3 Kimberlite anomaly.

The upper part represents the geophysical profile, intermediary portion shows vertical and horizontal gradient from profile data, and in the lower part, the depth estimative can be seen according to pre-defined parameters from the anomaly cause.

There is still another important magnetic anomaly in the region (Figure 2 - B4), corresponding to another kimberlitic intrusion (named Canastra-8 Kimberlite by the extinct SOPEMI-De

Beers). Although there are indicatives of diamond mineralization in this body (Chaves *et al.*, 2008a), its drainage pattern is directed to the south, flowing into the Peixoto's Dam in the Grande

River, and obviously, it could not be the source of Santo Antonio River's secondary deposits. However, in the same region (out of Figure 2 map) the Canastra-1 Kimberlite is mineralized at

economic level, with a grade of 16 ct/100 ton and an important average value

of their diamonds of US\$ 180-200/ct, whose mining was suspended because

of environmental questions, still under discussion (Chaves *et al.*, 2008b).

4. Chromium pyrope mineral chemistry

Considering that the Canastra-3 Kimberlite was the only intrusive body detected in the upstream portion of the Santo Antônio River basin, a detailed reconnaissance was made there. The current contact of the intrusion occurs

in low relief in the mountain range, with the quartzite of the Canastra Group (Figure 5-a). Due to the lack of fresh outcrops, this weathered material and its residual soil was sampled, in a cut at one of the headwaters of the Babilônia

Creek. (Figure 5-b). About 50 kg of material was sampled and milled at the site (Figure 6-a/b), from which heavy minerals were extracted by sieving concentrations in the thinner mesh of 1 mm (Figure 6-c/d).

Figure 4 - N-S “Euler Deconvolution” final profile processed on Canastra-3 Kimberlite anomaly, with the same specifications of the previous profile.

Figure 5: (a) Physiographic aspect from the area where the Canastra-3 kimberlite occurs, showing its low relief expression and dense vegetation. (b) Inside its deepest portion, there is a small lagoon, which constitutes one of the possible springs of Santo Antonio River.

Figure 6 - (a) Sample profile of altered rock and soil to heavy minerals concentration. (b) General aspect of this weathered rock. (c) Concentration process by gravimetry using sieving of the tired material. (d) Manual sampling of the heavy material to later laboratory study.

The field concentrate was further processed in the laboratory, and again separated into the sieve fractions 0.25 mm and 0.125 mm. Through binocular loupe examination, the minerals from alluvial prospecting were recognized by their optical properties, being identified as probable garnet, ilmenite and chromite. The red garnets with a strong purple hue (grapefruit, according to Mitchell, 1986) were the initial object of study by electron microprobe analy-

sis (Microanalysis Laboratory - DEFIS/ICEX-UFMG). The obtained results were surprising (Figure 7 - limits between mineral chemistry fields according to Rombouts, 2003 and Grütter *et al.*, 2004): from 41 analyzed grains, 19 were plotted in the G-10 garnet-type field (or about 46%), considered to have a very high potential for diamond prospecting (e.g., Dawson and Stephens, 1975; Grütter *et al.*, 2004).

The great majority of kimberlites

in the southwestern Minas Gerais State have already been shown to have a zero or negligible fraction of G-10 chromium pyrope, which are characterized by high levels of chromium and low calcium. G-5 and/or G-9 predominate in these kimberlite bodies (e.g., Esperança *et al.*, 1995; Cookenboo, 2005; Svisero *et al.*, 2005), leading to intense discussions on the enigmatic source of the diamonds from the Alto Paranaíba region.

Figure 7 - CaO x Cr₂O₃ diagram of representative samples of chromium pyrope from the Canastra-3 Kimberlite.

5. Conclusions

The occurrence of alluvial diamonds in Santo Antonio River's lower course, and the apparent absence of other kimberlite intrusions in its small dimension basin, allowed focusing the studies on the Canastra-3 Kimberlite, which shows strong magnetic anomaly. Based on

diamond mineral indicators and chemical mineral detailed analyses, the preliminary results showed that almost half of the sampled chromium pyrope is of the G-10 type, contrasting with the G-5/G-9 groups commonly present in majority of the kimberlites from western Minas Gerais.

These data point to the high potential of this intrusion and consequently, to the need for more detailed researches. The kimberlite also stands out as the first in Brazil to show (with published results) a significant percentage of the G-10 type pyrope group.

Acknowledgements

To the Italian-Brazilian geologist Luigi Giglio, the popular "Gino" (in memoriam), who indicated the position of the Canastra-3 Kimberlite to the first au-

thor, that also thanks FAPEMIG for supporting fieldwork and mineral chemistry analyses (Process CRA-APQ00165-08), and CNPq for the Research Productivity

grant. Acknowledgments are extended to an anonymous reviewer, who greatly contributed to the improvement of this paper.

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Received: 17 April 2018 - Accepted: 27 August 2019.