10IKC-273

MINERAL CHEMISTRY OF GARNETS AND ILMENITES OF THE PEPPER-1 AND COSMOS-3 INTRUSIONS, ESPIGÃO D'OESTE, RONDÔNIA, BRAZIL.

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INTRODUCTION

The study of kimberlitic indicator minerals, including garnet and ilmenite, is an important tool for diamond exploration. It brings preliminary information on diamond fertility of pipes, preservation or resorption of diamonds and characteristics of the mantle where they were formed.

Although kimberlitic intrusions are known in the field of Pimenta Bueno since the 70's after works done by SOPEMI (De Beers Group) and CPRM - Company of Research of Mineral Resources, few studies have been published, including Hunt et al (2009) that reported mineral chemistry of garnet and Cr-diopside of the Carolina kimberlite. In this work, major elements of garnet and ilmenite of the Pepper-1 and Cosmos 3 pipes, located approximately 50 km SE of Espigão d'Oeste (Figure 1), were studied.

GEOLOGICAL OVERVIEW

In the west portion of Brazil, in the Mato Grosso and Rondonia states, there are several kimberlitic fields identified in Figure 1 as Juína (JU), Paranatinga (PA), Pontes e Lacerda (PL), Colorado d'Oeste (CO) and Pimenta Bueno (PB). Pimenta Bueno intrusions are 225 to 240 Ma (Masun & Scott Smith 2008 and Hunt et al. 2009) and Juina intrusions are 92 to 95 Ma (Heaman et al. 1998). The Juina event has been related to the impact of the Trindade Plume (Gibson et al. 1997).

In the Pimenta Bueno kimberlitic field, there are over 30 kimberlitic pipes (Masun & Scott Smith 2008). The vast majority occurs within the Pimenta Bueno graben that was filled by permo-carboniferous sediments of the Parecis basin (Siqueira & Teixeira, 1993). The Pimenta Bueno Formation is older and deposited in glacio-marine environment and the Fazenda da Casa Branca Formation, on top, is related to and continental deposits. Pimenta Bueno Formation is the host rock of kimberlites intruded in the edge of the Pimenta Bueno graben and the Fazenda Casa Branca Formation covers some kimberlites in this field, including Pepper 1. On the other hand, the Carolina kimberlite intrudes basement rocks of the Paleo-Mesoproterozoic Rio Negro-Juruena Province (1.8-1.55 Ga; Macambira & Tassinari, 1999).

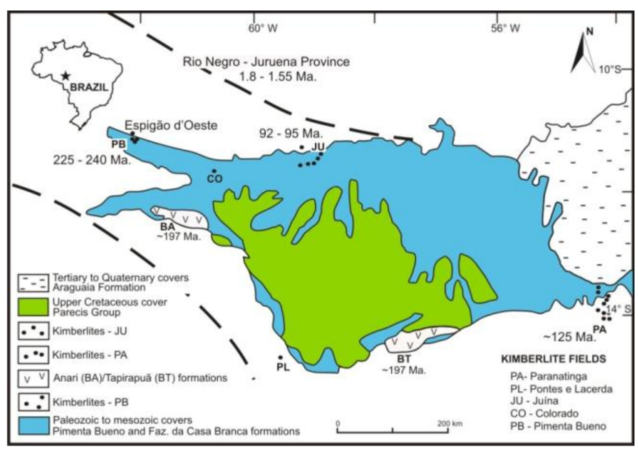

Figure 1. Geological map of Parecis Basin adapted from Siqueira & Teixeira (1993), with location of kimberlitic fields in Rondônia and Mato Grosso.

Preliminary macroscopic descriptions of both pipes show from top to bottom, red to brown volcaniclastic kimberlitic breccia (VKB) to gray to green volcaniclastic kimberlitic (VK) facies. Color variation is due to alteration. These facies are usually associated with pyroclastic rocks (PK), resedimented volcaniclastic kimberlite (RSVK) and reworked volcaniclastic kimberlite (RWVK) (Cas et al. 2008), which filled the crater zones of the Pepper 4 pipe (Masun Scott & Smith, 2008) and Pepper 1 and Cosmos 3 pipes. Most xenoliths in VKB are from Pimenta Bueno

Formation. They are mostly angular, ranging from imbricated microbrecias to mega xenoliths, sometimes matrix supported. To a less extent kimberlitic materials occur, such as rounded and serpentinized macro to megacrysts of olivine. In VK we note the increase in magmaclasts, rounded macro and megacrysts of olivine, matrix supported material, and sometimes pelletal lapilli(?). Carbonate occurs impregnated in the matrix of both pipes and as segregations of venules and veins. In addition to garnet and ilmenite, others kimberlitic indicators occur as macrocrysts of Cr-diopside in Pepper 1 and macro and megacrysts of phlogopite and rare macrocrysts of Cr-diopside and chromite in Cosmos 3.

METHODS

Garnet and ilmenite grains were extracted from cores of the drill holes PBDD13 (Pepper-1) and PBDD27 (Cosmos-3). Concentrates with xenocrysts indicators, in the fraction between 1 and 3 mm were obtained by sieving. In binocular lens, garnets and ilmenites were separated and mounted in polished sections.

Electron microprobe analyses were obtained with a JEOL JXA 8230, at the Geosciences Institute, University of Brasilia (UNB). Garnet xenocrysts were classified according to Grütter et al. (2004).

RESULTS

Garnets

Table 1 summarizes the compositional range of major elements of the different types of garnets found in Pepper 1 (n = 46) and Cosmos 3 (n = 39) kimberlites. They are plotted in the diagram Cr_2O_3 vs. CaO (Figure 2), with G - number classification according to Grütter et al. (2004). The scattering of the Cosmos 3 garnets, near the dividing line between G9/G10 is similar to that found for garnets from the Carolina pipe (Hunt et al. 2009).

Table 1. The minimum and maximum in wt.% of the major elements of garnets from Pepper 1 and Cosmos 3. The CA_INT, MGNUM and G-number classification (Grütter et al 2004) are indicated. n = number of grains; % - percentage of grains.

GARNET	PEPPER 1 *n*=46			COSMOS 3 *n*=39				
SiO_2	41-42	41-42	41	41-43	41	41-42	41-42	41-42
TiO_2	0.4-1.1	0.1-0.3	0.5-0.8	0.4-1.0	0.3	0.3	0.1-0.4	0.4-0.5
Al_2O_3	19-22	18-22	19	19-23	23	23	19-22	19-20
Cr_2O_3	0.9-3.8	2.5-6.9	4.5-5.2	0.4-3.7	0.6	0.3	2.1-6.1	4.1-5.2
MgO	19-22	20-21	19-21	19-22	17	19	20-21	21
CaO	4.1-5.9	4.3-5.7	5.2-5.7	4.1-5.7	8.7	4	4.2-5.6	5-5.1
MnO	0.2-0.5	0.3-0.5	0.3-0.4	0.2-0.4	0.1	0.3	0.3-0.5	0.3
FeO	7.2-9.3	7.3-7.8	7.1-7.8	7.2-10.3.	8	11	6.6-8.4	6.4-7
Na_2O	0.5-0.13	0-0.1	0.06-0.1	0.02-0.11	0.1	0.1	0-0.1	0.04-0.06
CA_INT	3.81-5.56	3.58-3.97	4.09-4.40	3.71-5.37	8.5	4.06-4.19	3.59-4.56	3.70-4.05
MGNUM	0.79-0.84	0.83-0.84	0.81-0.84	0.77-0.84	0.79	0.75-0.76	0.81-0.85	0.84-0.86
GARNET	G1	G9	G11	G1	G3D	G4	G9	G11
n	27	17	2	17	1	3	16	2
%	59	37	4	43	3	8	41	5

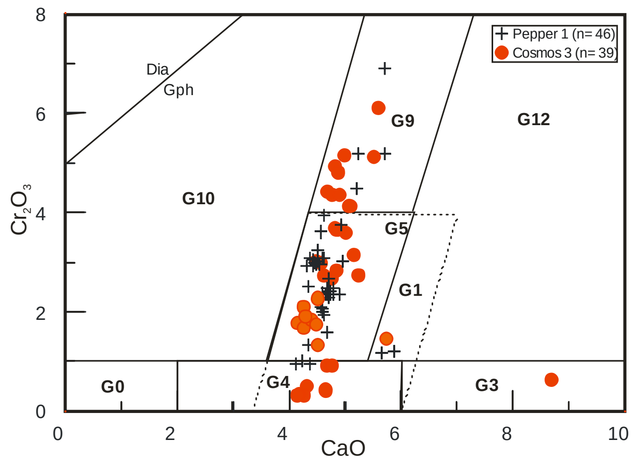

Figure 2. Conventional plot of Cr_2O_3 vs. CaO (wt.%), for garnets from the Pepper 1 and Cosmos 3 kimberlites, fields are group-number classification of Grütter et al. (2004).

Pepper 1 garnets are classified as G1, G9 (pyrope) and G11. Cosmos 3 garnets are G1, G9, G11, G4 and G3D (Table 1). G1 garnets predominate in both pipes with 59 and 43% of the total, respectively, followed by G9 with 37% and 41% and G11with 4 and 5%. In Cosmos 3 pipe G4 correspond to 8% and G3D 3%. Low-Cr suite of garnets megacryst of G1 group can be separated from G9 garnets because they have lower Cr contents, and higher Ti and Fe contents. G9 garnet can be separated from G5 group in their MGNUM index (MGNUM=(MgO/40.3)/(MgO/40.3 + FeOt/71.85) [oxides in wt.%], Grütter et al. (2004)). For G5 it ranges from 0.3 to < 0.7 while for G9 MGNUM is higher than 0.8 in Pepper 1 and Cosmos 3. The classification of the G11 garnet, proposed by Dawson and Stephens (1975, *in* Grütter et al.2004) as sheared peridotite garnet with high-TiO_2, and intermediate CaO and Cr_2O_3 contents were identified in both pipes. According to Grütter et al. (2004), G4 and G5 garnets clusters can be easily separated by their Cr_2O_3 and MGNUM contents. For G4, Cr_2O_3 is < 1 wt.% and MGNUM from 0.3 to < 0.90, while for G5, Cr_2O_3 varies from ≥ 1 to < 4 wt.% and MGNUM from ≥ 0.3 to < 0.7. In G4 garnets (n=3, see Table 1) identified in the Cosmos 3, Cr_2O_3 is 0.3 wt.% and MGNUM ranges from 0.75 to 0.76. The only G3D garnet found in this study, in Cosmos 3 pipe, stands out from other groups due to the high content of CaO (8.7 wt.%) and low Cr_2O_3 (0.6 wt.%). Grütter et al. (2004) consider that the suffix "D" with composition connotations should be used when Na_2O is > 0.07 wt.%.

Garnet harzburgite (G10) with high Cr_2O_3 and low CaO contents were not found in our study. G10 garnets are important indicators of fertile diamond pipes, as found in kimberlites in South Africa and Siberia. G9 garnets and G3D or G4D and G5D are also important indicators to find fertile diamond pipes. The G3D garnet found in Cosmos 3 suggest a close association with diamond.

Ilmenites

MgO-rich ilmenite (picro-ilmenite) and varieties with low to high-Cr_2O_3 can coexist with diamondiferous kimberlites. Ilmenite with high MgO and Cr_2O_3 and low Fe_2O_3 are ideal for the preservation of the diamond. Nevertheless, there is no genetic relationship between the ilmenite and diamond (Semytkivska, 2010). Ilmenite is used as an indicator because it is abundant in kimberlite, it is resistant to weathering and records the fugacity conditions (fO_2) during crystallization or intrusion.

A total of 105 analyses of grains from Pepper 1 (n=44) and Cosmos 3 (n=61) pipes were performed (Table 2). Ilmenite occurs as macrocrysts to polycrystalline megacrysts (2 cm) in Pepper 1 pipe. In Cosmos 3 pipe ilmenites are found as macro and megacrysts (~ 1.3 cm). In both pipes some ilmenites suggest pumps of explosive magmas or of phreatomagmatic explosive activity.

Table 2. Range of major elements (wt%) of ilmenites from Pepper 1 and Cosmos 3 pipes. n – number of grains.

ILMENITE	PEPPER 1 n=44	COSMOS 3 n=61
MgO	9.5-15	9.7-14.1
Al_2O_3	0.1-0.6	0.1-0.6
Cr_2O_3	1-2.2	1-3.2
TiO_2	49.5-54.5	48.6-54.7
NiO	0.05-0.3	0.04-0.2
MnO	0.2-6.3	0.2-0.8
FeO_t	23.6-36.3	27.4-36.5
V_2O_3	0.3-0.6	0.3-0.5
Nb_2O_5	0.1-0.4	0.1-0.4

The compositional range of ilmenites from Pepper 1 and Cosmos 3 pipes is similar (Table 2), except for higher MnO (wt%) content in Pepper 1 and higher Cr_2O_3 (wt%) content in Cosmos 3. Kaminsky et al. (2009) reported that typical kimberlitic ilmenite contains 0.2–0.3 wt.% MnO and sometimes up to 0.5 wt.%. Magnesium-rich ilmenite has conventionally been interpreted as an indicator of kimberlite associations, as well as an indicator of low fO_2, which is necessary for the survival of diamond (Garanin et al., 1997; van Straaten et al., 2008, *in*: Robles-Cruz et al., 2009).

Ilmenites from this study are classified as kimberlitic in the diagram TiO_2 vs. MgO (Figure 3) according to Wyatt et al. (2004). This diagram separates kimberlitic from non-kimberlitic ilmenite.

In the diagram MgO vs. Cr_2O_3 (Figure 4) most ilmenites from both pipes plot on the right hand branch of the parabola, which is indicative of kimberlites with higher diamond contents than those to the left (Semytkivska 2010).

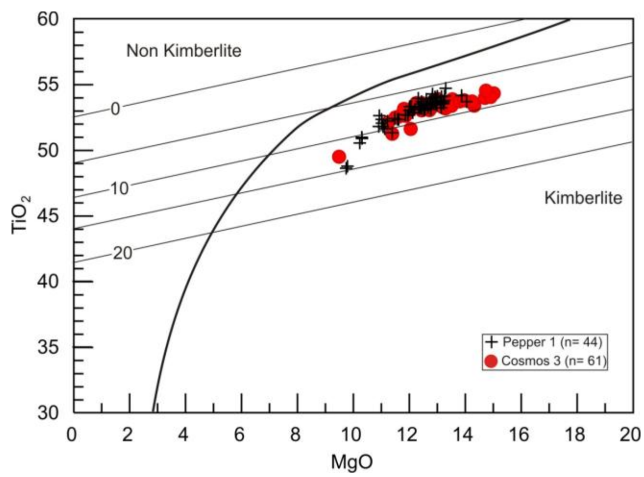

Figure 3. MgO vs. TiO_2 (wt%) for ilmenites from de Pepper 1 and Cosmos 3. The solida line separates kimberlitic from non-kimberlitic ilmenite. Parallel lines indicate Fe_2O_3 (wt%) content (Waytt et al. 2004).

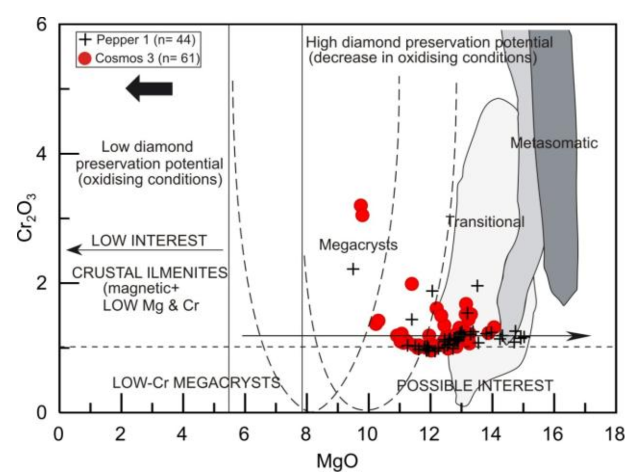

Figure 4. Schematic correlation between oxidation state, MgO vs. Cr_2O_3 content in wt.% of ilmenites from Pepper 1 and Cosmos 3 and diamond grade, after Semytkivska (2010).

In the diagram Fe_2O_3 *vs.* MgO (Gurney and Zweistra 1995), in wt% content, most ilmenites from Pepper 1 and Cosmos 3 fall in the domain of "preservation of diamond", and coincide with the field of the Premier Mine, South Africa (Figure 5). Catoca kimberlite in Angola, which is diamond mineralized, is an exception to this model, where more than 70% of the grains of ilmenites have high content of Fe_2O_3 wt.% and in a Fe_2O_3 vs. MgO, compositions fall in the domains of marginal to no preservation diamond (Robles-Cruz et al., 2009).

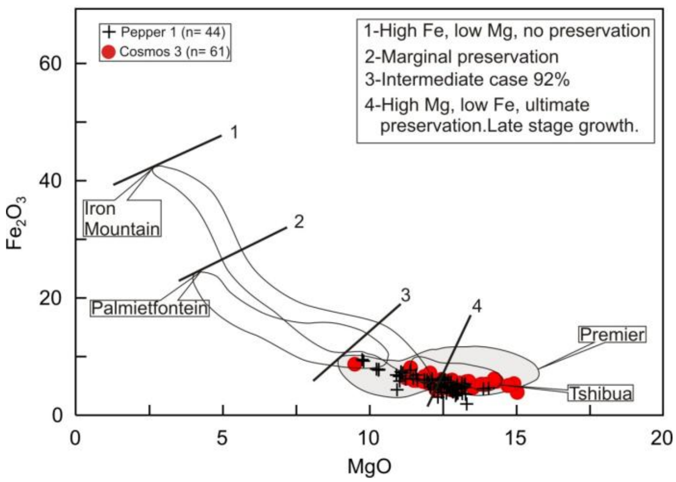

Figure 5. Fe_2O_3 *vs.* MgO (wt%) of ilmenites from the Pepper 1 and Cosmos 3 pipes. Fields are from Gurney and Zweistra (1995).

CONCLUSIONS

According to Grütter et al. (2004)'s classification, mantle derived garnets in Pepper 1 pipe are G1, G9 and G11 and in the Cosmos 3 pipe they are G1, G9, G11, G4 and G3D. Both pipes have predominantly lherzolitic garnets (G1 and G9) and subordinate G4 and G3D eclogitic garnets occur in Cosmos 3 pipe. Garnets of the G3D group (Type 1) have been associated to zones of intense melt-related metasomatism in adjacent peridotites and suggest a close association with diamond (Griffin & O'Reilly 2007).

Ilmenites from Pepper 1 and Cosmos 3 pipes are similar in composition except for the higher MnO (wt%) content in Pepper 1 pipe and the higher Cr_2O_3 (wt%) content in Cosmos 3 pipe. They have high MgO (wt%) and low Cr_2O_3 and Fe_2O_3 (wt%) contents. The low-Fe_2O_3 indicates favorable conditions for the survival of diamond.

ACKNOWLEDGEMENTS

The authors would like to thank Vaaldiam Resources Ltd. by allowing access to the boreholes Pepper 1 and Cosmos 3 kimberlites and the Laboratory of Electron Microprobe at the Geosciences Institute, University of Brasilia (UnB).

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