

# MINERALOGY OF DIAMONDS FROM THE JUINA PROVINCE, BRAZIL

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## INTRODUCTION

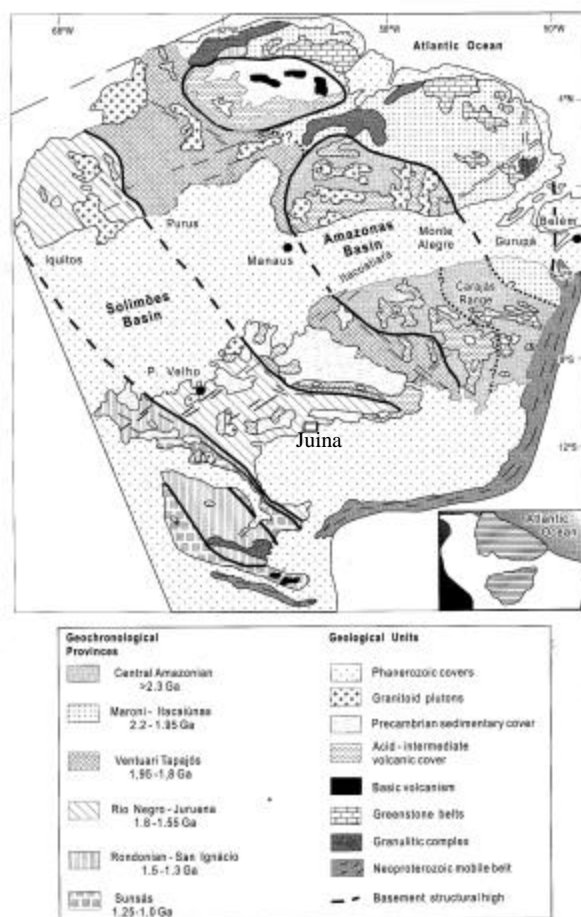
The Juina Kimberlite Province at the SW border of the Amazon Craton, Brazil (Figure 1), is a well-known site for deep diamonds originated in the transition zone (TZ) and lower mantle (LM). They have been recovered from the São Luiz River (Wilding *et al.* 1991, Harte and Harris 1994, Hutchison 1997) and other local drainages (Kaminsky *et al.* 2001). The Province intrudes the Rio Negro-Juruena Mobile Belt (1.8–1.5 Ga; Figure 1). Rb/Sr (kimberlite mica and whole rock; Bizzi, 1993) and U/Pb (kimberlitic breccia zircons; Heaman *et al.* 1998) methods yield ages of 198 and 92–95 Ma, respectively, for the Juina Province.

Our results reinforce the deep origin for alluvial diamonds from the Juina Province and allow us to expand this interpretation for most primary and alluvial diamonds. They also contribute with new data to the understanding of this important occurrence.

## METHODS

Methods used in this study were cathodoluminescence (CL), infrared spectroscopy (IR), carbon and nitrogen isotopes and N content measurements by secondary ion mass spectroscopy (SIMS). 188 primary diamonds from 3 kimberlites and 46 alluvial specimens from the rivers São Luiz (10), Duas Barras (8), Porcão (8) and Cinta Larga (20) were examined. CL images were obtained from 128 pieces of diamonds and 32 plates using an ELM-3R Nuclide Corporation luminoscope at the Geoscience Institute of the University of São Paulo and at the Department of Mineral Science of the Smithsonian Institution (SI). CL images from both sides of the plates were generated in order to check for matching features for further IR investigation. All diamonds were measured for IR using a microFTIR Bio Radius Excalibur spectrometer (60 to 440  $\mu\text{m}$ ) at the SI. IR traverses of 4 plates were performed at the National Synchrotron Light Source at the Brookhaven National Laboratory. The synchrotron source yielded

high quality spectra with spatial resolution of 15  $\mu\text{m}$ . C and N isotopic and N content *in situ* variation for 20 diamonds were measured through SIMS at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The methods used are detailed elsewhere (Araujo 2002).



**Figure 1** – Major geochronological provinces and main lithological associations of the Amazon Craton (Tassinari *et al.* 2000). The Juina Kimberlite Province is depicted by the rectangle.

## RESULTS

Diamonds are mostly resorbed fragments, tetrahexaedral and irregular, though regular octahedral and macles are described. Primary and alluvial diamonds could not be distinguished according to their morphological characteristics. CL images for most part of the diamonds present typical blue-sky color, but with low intensity. Most stones exhibit homogeneous CL patterns. Rare internal features were observed, which were octahedral growth zones, step-wise growth, truncated growth zones and fine parallel lines, the later two features being evidence for resorption and deformational processes. An example is depicted in Figure 2. Resorption after-growth features, revealed both by binocular loupe and CL investigation, are common amongst the Juina diamonds.

Type II diamonds (N-free) predominate among alluvial and primary stones (82%). The minority Type I diamonds present low-N content (up to ~ 300 at. ppm, except for one specimen with 613 at. ppm of N – SIMS determination) and were classified as IaAB (24 stones) and IaB (6 stones). Except for three stones, IaAB diamonds are highly aggregated (> 90%). The abundance of Type II stones agrees with the high number of low intensity CL diamonds.

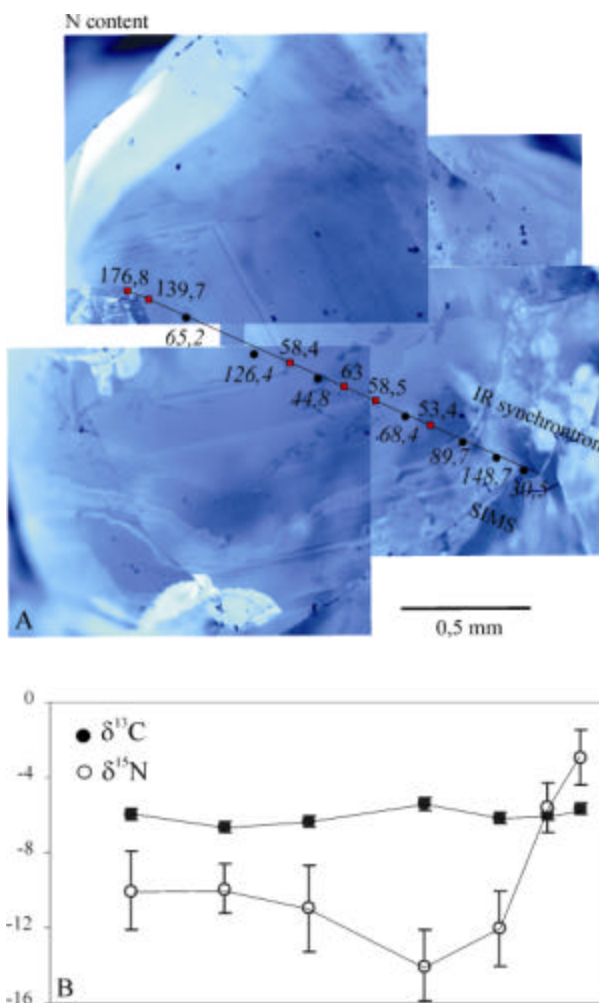
$\delta^{13}\text{C}$  for Type II diamonds varies from – 3 to – 26.3‰ and for Type I from – 3.4 to – 13.8‰. The  $\delta^{15}\text{N}$  interval for Type I diamonds ranges from +2.2 to – 14.0‰ and the N content, from 3.85 to 613.74 at. ppm.

The Internal chemical variation was measured for N content (4 stones; IR-synchrotron and SIMS) and for C and N isotopes (6 stones; SIMS). One example, as depicted in Figure 2, is an IaAB octahedral diamond which showed CL matching features on both sides of the plate. N determinations are similar comparing both methods and N is highly aggregated all over the stone (97,7-100%).  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  variation for this specimen is illustrated below (Figure 2B). As happens for most stones,  $\delta^{13}\text{C}$  shows a monotonous trend compared to the high variation of  $\delta^{15}\text{N}$  through the diamond (-14 to –2,9‰ for this specimen).

## DISCUSSIONS AND CONCLUSIONS

$\delta^{13}\text{C}$  data for Type I and Type II diamonds (this study) are compared in Figure 3 with those for worldwide upper mantle assemblages (Cartigny *et al.* 1999, bars below the diagram) and to deep diamonds from Juina (Hutchison 1997 and Kaminsky *et al.* 2001) and from

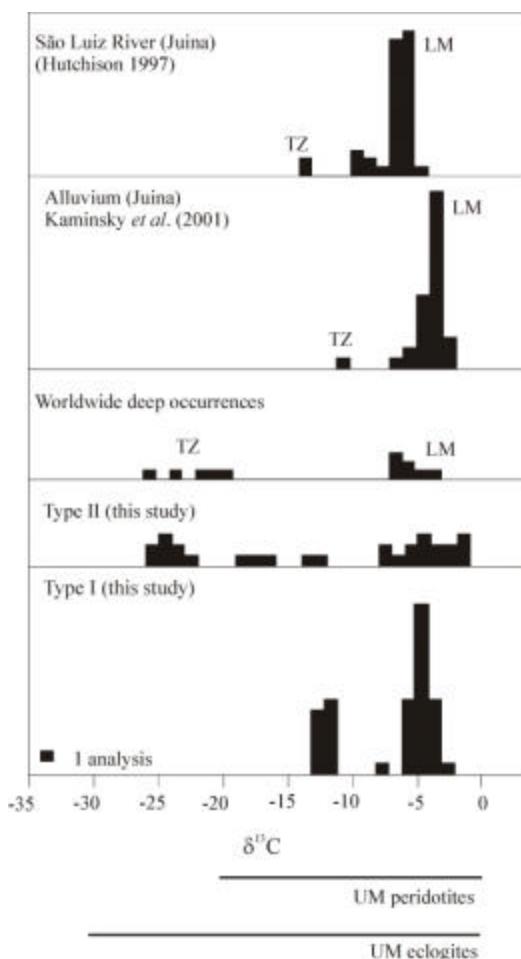
worldwide occurrences: Koffiefontein, Jagersfontein (Deines *et al.* 1991), Guinea (Hutchison 1997) and Lac de Gras (Davies *et al.* 1999). Our results suggest the existence of four sets of data concentrated near -5‰; -13‰; -18‰ and -25‰, where Type I diamonds belong only to the first two groups. We, therefore, do not exclude the possibility that blanks in this interval could be attributed to lack of sampling.



**Figure 2** – A) Mosaic depicting CL image of a resorbed octahedral diamond (TR2-3). The values correspond to N content measured by SIMS (black dots, values in italic under the line) and by IR synchrotron source (red squares, values above the line, 15  $\mu\text{m}$  spatial resolution). N content measured by both methods are similar. Note the low N content (65,2 at. Ppm, first black circle on the left) measured in a dark region, which is probably the center of the stone. B)  $\delta^{13}\text{C}$  (black circle) and  $\delta^{15}\text{N}$  (open circle) variation. The transverse correspond to SIMS determinations (black circles) in A.

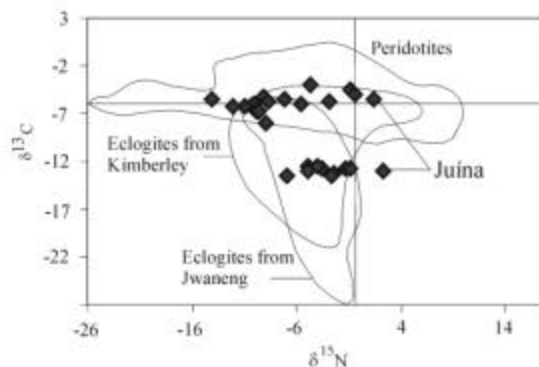
The  $\delta^{13}\text{C}$  interval obtained here is expanded toward lighter values if compared to previous results:

Hutchison (1997) and Kaminsky *et al.* (2001) observed two sets of data, one distributed near -5‰ and other in the approximate interval between -11 to -13‰. Transition zone (TZ) diamonds have been related to both groups while lower mantle (LM) diamonds concentrate around -5‰, indicating the homogeneous carbon isotopic character of the LM (Hutchison 1997 and Kaminsky *et al.* 2001). Data for worldwide LM diamonds also cluster around -5‰ while TZ diamonds from Jagersfontein are in the interval between -20 to -25‰ (Deines *et al.* 1991).



**Figure 3** -  $\delta^{13}\text{C}$  composition of diamonds from the transition zone (TZ) and lower mantle (LM) from the Juina Kimberlite Province (Hutchison, 1997 and Kaminsky *et al.* 2001), of TZ and LM worldwide diamond occurrences (see text for locations and references) and from Type I and Type II stones studied here. Upper mantle (UM) peridotite and eclogite diamond  $\delta^{13}\text{C}$  compositions (Cartigny *et al.* 1999) are indicated by the bars below the diagram for comparison.

The  $\delta^{15}\text{N}$  composition for the Juina diamonds (+2.2 to -14.0‰) encloses previous results from Hutchison *et al.* (1999), that reported -5.2‰ and -6‰ for LM stones and +1.3‰ and +1.2‰ for TZ diamonds. Ample compositional intervals were observed here for single diamonds (e.g. -14 to -2.9‰ and -9.6‰ to +2.2‰), and are within the compositional range for  $\delta^{15}\text{N}$  data for worldwide diamond occurrences, as seen in Figure 4. Ample intervals have also been reported for diamonds from Mir and Udachynaya, Russia (Hauri *et al.* 1999; Figure 4). The ample  $\delta^{15}\text{N}$  variation for single stones and the observed oscillatory patterns suggest the high sensibility of the nitrogen isotopic system in diamonds. Taking it into account, one may be caution when using positive  $\delta^{15}\text{N}$  to trace re-cycled carbon.



**Figure 4** -  $\delta^{13}\text{C}$ -  $\delta^{15}\text{N}$  Co-variation for diamond occurrences. Fields for worldwide peridotite and for eclogites from Kimberley and Jwaneng are from Cartigny *et al.* (1998a and 1998b). Filled symbols are Type I diamonds from this study. The vertical line is the atmospheric  $\delta^{15}\text{N}$  value (Mariotti 1983) and the horizontal line is the primordial composition for  $\delta^{13}\text{C}$  (-4.6‰).

As observed for deep diamond assemblages, the Juina Kimberlite Province contains elevated percentage of Type II diamonds (82%) and highly aggregated Type I stones, indicating high temperature and/or long time of mantle residence. Considering the rarity of Type II diamonds in the upper mantle and the high aggregation of N in Type I diamonds, we suggest that the majority part of diamonds investigated here were originated in the LM and TZ.

The abundance of Type II diamonds in the TZ and LM suggests the existence of particular conditions that avoid N incorporation by diamonds. The formation of osbornite ( $\text{TiN}$ ) and sinoite ( $\text{Si}_2\text{N}_2\text{O}$ ) and/or N exsolved in silicates are suggested in the literature. An alternative explanation for N-free diamond formation

is the elevated temperature of TZ and LM. This is suggested here based on diamond synthesis experiments performed by Burns *et al.* (1999) that showed the decrease of N incorporation by diamond as the N solubility of the environment increases, which, on its turn, increases with temperature.

The light composition of  $\delta^{13}\text{C}$  for Type II diamonds, down to  $-26,3\%$ , may indicate that the TZ below the SW Amazon Craton was influenced by re-cycled carbon, which would be in accordance with subductions that originated the Rondoniana Santo Ignácio and Sunsás terrains between 1.5 to 1.0 Ga at the SW border of the Amazon Craton.

## ACKNOWLEDGEMENT

The authors are greatly thankful to RTDM Ltd. and De Beers Brasil Ltd. for providing the diamonds for this study, to Gergely Szabo from the University of São Paulo and Jamies Rougvié from the Smithsonian Institution for CL images, to Richards Wysoczanski from the Smithsonian Institution and to Lisa Miller and Zhenxian Liu from the Brookhaven National Laboratory for IR measurements.

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