DIAMONDS FROM THE MACAUßAS RIVER BASIN (MG, BRAZIL): CHARACTERISTICS AND POSSIBLE SOURCE

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ABSTRACT
Physical characteristics of diamonds from the Macaúbas River Basin are described based on a ten-point scheme. They have been statistically treated and combined with results of heavy mineral analyses in stream concentrates, as well as with features of ancient and modern sediments. Preliminary results point towards an extra-basinal host igneous rock area lying in the north-northwest. These igneous rocks underwent erosion and the diamonds suffered a gentle fluvial transport. During the Proterozoic São Francisco Glaciation the diamonds were redistributed and deposited in glacial sediments in the proto-Macaúbas River Basin area. Recent fluvial processes eroded these diamonds from the diamondiferous tillites into stream sediments.

Keywords: Diamonds Characteristics, Macaúbas Basin, Glaciogenic Rocks

INTRODUCTION
The Macaúbas River, a northwest tributary of the Jequitinhonha River, is located in central-north Minas Gerais State (MG), Approximately 400 km north of the State’s capital Belo Horizonte (Fig. 1). The area of 1000 km² is relatively unpopulated with only a few and hard to access dirt roads. Although diamonds have been washed in this region for over 200 years, the first scientific study is attributed to Moraes (1932), who introduced the stratigraphic term “formação Macaúbas” for a conglomeratic sequence of glacial origin. Hattieh (1977) and Karfunkel & Karfunkel (1977) carried out the first detailed stratigraphic subdivision and proved definitively a glacial origin for the central diamicritic unit of this Group of Proterozoic age.

Karfunkel et al. (1984) and Karfunkel & Hoppe (1988) elaborated a model which advocated for a continental glaciation about 1 Ga ago, during which the São Francisco Craton was covered by ice that left its trace in eastern, western, and southern lying fold belts. This event of cold climate has been dated by Pedrosa-Soares et al. (2000) between 950-850 Ma and has been named by Karfunkel et al. (2000) the São Francisco Glaciation.

Although some authors (e.g. Fleischer 1995, 1998, Almeida-Abreu 1996) postulate the occurrence of diamondiferous pipes in the Espinhaço Range (MG) primary diamondiferous rocks are to date, not known from this region (Karfunkel et al. 1994). The oldest mineralized secondary rocks are diamondiferous metaconglomerates belonging to the Mesoproterozoic Sopa-Brumadinho Formation (± 1.7 Ga) of the Espinhaço Supergroup, Gonzaga & Tompkins (1991) describe a glacial transport with fluvial recondensation of diamonds during later events. An upheaval of the Canastra Arch (Haralhy & Hasui 1983) and the Espinhaço Range (Karfunkel & Chaves 1995) during early Cretaceous time gave rise to the formation of the Proto São Francisco and Jequitinhonha rivers, and diamonds have been reworked from these older sequences into both river systems (e.g. Campos et al. 1993, Karfunkel & Chaves 1995, Chaves & Karfunkel 1997). The youngest redistribution of

Figure 1 - Map of the Macaúbas River Basin with its local geology.

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Diamonds occurred during Plio-Pleistocene and Holocene time, and recent drainage systems are today the most important sources of diamonds in the Espinhaço Range.

Although diamond exploration in the Macaúbas River Basin in terraces and recent river gravel is similar to other occurrences of the Espinhaço Range, there is a key difference: the Macaúbas Basin and the northern lying, smaller Congonhas Basin are the only places in the State, in which carbonados in notable quantities occur together with diamonds. These and the lack of detailed studies led Martins et al. (2000) to map this area and to study the diamond occurrence.

About 85% of the Macaúbas River Basin is composed of glaciogenic metasediments of the Macaúbas Group (Fig. 1). Quartzites and locally non-diamondiferous metaconglomerates of the Espinhaço Supergroup comprise the remainder. Remnants of Cretaceous conglomerates have been described by Martins et al. (2000).

The present paper provides a contribution to diamond characteristics of the Macaúbas River Basin. Preliminary statistics of these characteristics are combined with sedimentological features of the Proterozoic glacial and Recent sediments to elucidate possible sources for diamonds from the Macaúbas River Basin.

METHODS To examine diamonds from the Macaúbas River Basin is a difficult task. Today, only a few diggers wash diamonds in these remote areas, accessible only by foot. Therefore the majority of diamonds has been examined in loco, using portable equipment. Diamond descriptions were conducted using a 10X triplet hand lens (for geological graduation), as well as a zoom binocular loupe (10-60 X magnification) and a hand scale. The description scheme is outlined in Tab. 1, and is based on the schemes devised by other authors (e.g. Robinson 1979, McCallum et al. 1994, McCandless et al. 1994, Otter et al. 1994), with some modifications.

Diamond size has not been grouped according to sieve classeX-

| Table 1 - Classification scheme for the diamond characteristics of the Macaúbas River Basin. |
|---|---|---|
| 1. ID + ct | 5. Radiation Spots | 8. X-Regularity |
| 3. Appearance | 7. Morphology | 10. Surface Features |
| 4. Coat | [Additional comments] | |

Explanation and/or [e.g.]:
1. [JMP-011] 0.21 ct; 2. a. Color + hue + intensity (Pale, Medium, Dark) [I = brownish Pale]; b. Clarity (P1); 3. Shiny or Frosty; 4. Coating color + Intensity (Green + Pale); 5. Radiations Color [Brown], shape (round, square, rectangle, irregular, others). Size (examined with the binocular loupe at 10X magnification relative to each host crystal size, similar to the relative geological graduation of the clarity. Large, Medium, Small, and density (a relative term to describe the space distribution of several or many Radiations Spots. Dense, Medium, Scarse, others with description). 6. Description of the inclusions.
7. General comments (if any) 2. a. Single X-Forms (Octahedron, Cube, Transition) - Twinned (Mate) - Others
b. Modified from Otter et al. (1994) by joining category 6 and 5 Resorp. Cat. % Preserv. R.C. % Pre R.C. % Pre R.C. % Pre R.C. % Pre
90-100 4 80-89 370-79 2 50-69 1 < 50
8. Nearly Equidimensional, Intermediate, distorted (in all three categories only if > 50% of the crystal is preserved), not identified.
9. Whole, broken (including cleavage), not identified.
10. General comments (if any)
   a. magmatic (e.g. Etch Features, Hillocks, Primary Cleavage, Inclusion Pits, Lamination Lines)
   b. sedimentary (e.g. Wear on Apex, Percussion Marks, Secondary Cleavage); [Additional comments] - [Several large Gloses reaching diamond surface] or [wear on edges are dubious. Needs SEM].

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weighing less than 0.10 ct (Fig. 2), a class referred to by diggers and local dealers as “Fazenda Fina”. This dominance of small diamonds could be, in part, the consequence of working previously washed gravel, where most larger stones have already been exploited. Diggers report isolated findings of larger stones years ago, the largest being seven carats and recovered in 1993. The smallest recovered diamond in the present study weigh 0.019 ct.

**Gem Quality**  Geological evaluations of secondary diamond deposits and of sedimentological processes are based on gemological grading of stones (e.g. relation between gem and industry diamonds, medium quality of population in diamond deposits), which implies in a commercial point of view. Small diamond of excellent quality are geologically “interesting”, but are of no commercial value for the gem market (e.g. the smallest cut brilliant has a weight of 0.000102 ct, Malzahn, 2000). Statistics concerning “gemological features” of deposits are therefore to some degree imperfect, and should take into consideration all sizes of diamonds recovered in a deposit.

Changes in the division between gem and industrial stones has been suggested by Levinson (1992) to be called suitable and industrial, to take into account market oscillations. However, again it limits the possibility of carrying out reliable geological studies that include stones < 0.01 ct in weight.

For this study, we suggest a division in *gem-like* and *industrial-like* diamonds. This scheme implies in an evaluation of quality, regardless of commercial point of views (e.g. their size). In this way also very small diamonds or microdiamonds (< 1 mm according to McCandless et al. 1994) can be incorporated into the statistics.

In a gemological context our suggested classification is a contradiction to existing rules, because grading of cut stones has to be carried out with a daylight-type illumination and a triplet hand lens 10 X magnification. Under such conditions small and microdiamonds cannot be graded. For geological field assessment, however, it is useful to use a less restricted scheme for rough, joining several color and clarity categories in one and the same group, and using even a binocular loupe. In this way the classification of very small diamonds (and even microdiamonds) has the connotation “They look like gem diamonds. If they would have been larger they could be classified (probably) as gem diamonds”. Thus we divided the Macaúbas diamonds into ‘gem-like’ and ‘industrial-like’ diamonds.

As shown in Fig. 3, 72.6% of the diamonds belong to Group 1 and 2 Colors, and 71.9% to Group 1 Clarity. Only two stones have been classified as fancy (brown). This reflect, preliminary, the quality of Macaúbas diamonds, being medium and lower Colors with a good Clarity.

**Appearance**  Frosting have been classified by McCallum et al. (1994) as coarse, medium, fine, and very fine, and have been explained as late stage magmatic features, not restricted to any particular surface. In a similar way Meyer et al. (1997) describe a frosted surface which resulted not from abrasion, but more likely is the result of gas etching.

Due to our limited equipment we did not divide the diamonds into the above mentioned classes, but observed a variety of coarse, medium and fine frosting. Almost one fifth

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**Figure 2** - Weight distribution expressed as percent of total diamonds examined (N=253).

**Figure 3** - Relation between gem-like and industry-like diamonds and color/clarity categories of Gem-like diamonds in percentage.
(18.8%) of all examined stones show frosting (e.g. Fig. 8 A, E), which is, to some degree, of commercial importance for diggers and local dealers.

**Coat** In the Espinhaço Range 25% of diamonds have a green coat, which can be locally as high as 90% (Chaves et al. 1996). In this category the surface coat color (not the body color), as well as the mottled diamonds have been included. Color and intensity of the coat is due to radiation damage in situ (e.g. Vance et al. 1973) or resulting from the presence of minor elements in this coat (e.g. Orlov 1977). Chaves et al. (this volume) discuss these two hypotheses for Espinhaço diamonds.

We separated diamonds with a thin homogeneous surface color from those of surface mottled stones. Only two of the 253 examined diamonds showed a homogeneous medium green coating, an extremely low number compared to reports of other localities in the Espinhaço Range.

**Radiation Spots** Radiation Spots, similar to homogeneous surface colored diamonds, are the result of irradiating environments (radioactive minerals and/or radioactive solutions). A total of 56.6% of all examined diamonds (Fig. 4) show radiation spots. The spots usually have a round or oval shape, but square and rectangular patches have also been observed. They can be described as dense, medium or sparsely isolated spots regarding their arrangement and size.

Spots show in their central part higher color intensities relative to their circumference area (see also Banko 1997). Some intense green spots give the impression of black spots. This could be the reason for the high percentage of black spots in the statistics, but actually black (?), intense green, and green spots total 77.6%, which is in agreement with Banko (1997) and Chaves (1997).

Spots of different colors can occur on the same crystal. In some diamonds, rectangular, dark-green patches occur in juxtaposition with brownish to yellow spots with identical shape. This is the consequence of long contact with a radioactive mineral (e.g. monazite, xenotime) resulting in the dark green color, then repositioning of the radioactive mineral relative to the diamond, resulting in a new radiation spot of identical shape. Vance et al. (1973) describe a similar type of damage on diamonds, attributing it to a-particle irradiation. Heating about 600°C has also been suggested to be able to change the original green color to brown (Vance et al. 1973). However, detrital diamonds from the 2.5 Ga Witwatersrand exhibit both green and brown spots, though the diamonds have all been exposed to greenish faces metamorphism. The spots are actually graphite, which forms upon conversion of the mechanical energy of the a-particle to thermal energy. The green or brown color of radiation spots is purely a consequence of the duration of a-particle damage and the initial concentration of the U-bearing mineral (McCandless, unpublished data). This suggests that the irradiation is from minerals with high U contents, such as from detrital heavy minerals in the sedimentary environment (monazite has been identified by x-ray diffraction). Movement of the radiogenic mineral relative to the diamond results in new spots being formed. The patterns suggest that some of the Macaúbas diamonds were in a secondary deposit for an extended period of time, before being eroded into Recent river systems.

The round to oval spots are difficult to reconcile with diamond in contact with crystalline radioactive minerals. It has been established by studies elsewhere, that these features are likely to be produced by radiogenic fluids in contact with diamonds. The radiogenic fluids result from the decomposition of U-bearing heavy minerals that concentrate with the diamonds in secondary environments, again supporting the deposition of some Macaúbas diamonds in secondary deposits of old geologic age (McCandless, unpublished data).

**Inclusions** Only in very few diamonds, mineral inclusions such as garnet and olivine could be identified visually (Banko, personal communication). In gemological terms gletzes (fractures) are inclusions too. About one fifth of the examined stones show one to several gletzes. Some reach diamond surface (of primary or secondary origin ?), whereas others are internal and interpreted as possible tension cracks reflecting primary magmatic conditions.

**Morphology** Pristine unresorbed macrodiamonds are rare in nature (Robinson 1979), whereas preserved xenocryst microdiamonds are more abundant in some sampled primary igneous rocks. McCandless et al. (1994) showed a model to explain the degree of preservation of these microdiamonds in a resorbing magma, by protection in xenolith material.

In the stones 16.2% have been classified as "not identified". No Cube or unresorbed octahedra with perfect plane faces were observed. Octahedra with some degree of modification by tetrahedroid rounding (according to the terminology of Robinson et al. 1989), which have been called octahedroid by Orlov (1977), make up less than one fifth of our examined single crystal forms. Only 3.8% are twinned, being contact twins which are called by diggers "Chapéu de Padre". The remainder majority of stones are classified as transitions (octahedron to Tetrahedroid) and Tetrahedroid.

As to the secondary morphology, Tab. 2 shows the percent distribution in the five resorption categories (e.g. Fig. 7 C, E and G).

Two of the examined diamonds show uneven resorption, which results, according to Robinson et al. (1989), from partial protection during resorption within a xenolith.

**X-Regularity** The Macaúbas diamonds have been grouped in four categories as shown in Table 3 (e.g. Fig. 6 A, C, 8 E). Distortion is a function of a non-uniform development of faces during crystallization and is not related to deformation (Otter et al. 1994). Some examined diamonds show an

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**Figure 4 - Relation between diamonds with and without radiation spots and percent of color of these spots.**
“aerodynamic’” or “dogtooth” shape (according to Meyer et al. 1997) and have been classified as “not identified”.

**X-State**
Half of the analyzed diamonds (50.4%) have been classified as broken (mostly cleaved). Based on the sequence of magmatic events (e.g. Robinson et al. 1989, McCandless et al. 1994), we classified the nature of cleavages as primary (magmatic exhibiting etch features, e.g. Fig. 5 A, B) or of secondary origin (sedimentary, e.g. Fig. 5 C, D, E, F). 77.8% of the cleaved stones show etch features on their cleaved plane(s) and proved to be of primary (magmatic) origin. About one fifth of the cleaved stones (18.9%) have no etch features on the cleaved plane(s), and exhibit larger wear on edges and/or apices (e.g. Fig. 5 E, F, 8 D, F). These cleavage planes could reflect consequences of sedimentary impact. Only 3.3% of the cleaved diamonds were classified as having cleavage of unknown origin.

**Surface features**
It is difficult to distinguish between primary (magmatic) and secondary (sedimentary) surface features without the use of high resolution equipment (e.g. scanning electron microscope). The terminology used to describe surface features of the examined diamonds is based on Robinson (1979) and Robinson et al. (1989). They refer to the resorbed form as a “tetrahedraiform” in contrast to the commonly used “rounded dodecahedron” or “dodecahedraiform” used by Orlov (1977). According to McCandless (1989) this is important when considering microdiamonds and diamonds from xenoliths in which flat-faced dodecahedra can occur. Xenocrystic surface features are dominant amongst microdiamonds in Arkansas lamproites (McCandless et al. 1994) and result when resorbing volatiles in the host lamproite or kimberlite have restricted access to the diamond, due to adjoining mineralogical phases. They show features such as knob-like asperities, serrate laminae, tetragonal pitting and crescentic steps. On the other hand, among the macrocrystic surface features other aspects predominate (e.g. hillocks, low relief surfaces).

Lamination lines are created according to Urusovskaya & Orlov (1964) by slippage along glide planes in the diamond due to plastic deformation. They indicate ductile deformation when enclosed in peridotite or eclogite at mantle conditions (McCandless et al. 1994). According to Robinson et al. (1989) graphitization along planes in diamond may account for the correlation between lamination lines and brown color of stones from primary rocks.

The examined diamonds from the Macaubas River Basin have 42% with lamination lines (e.g. Fig. 8 A, B). They are usually closely spaced and parallel linear, and are most obvious on tetrahedral faces produced by resorption. Few stones show cross-hatched lamination lines associated with shagreen (e.g. Fig. 8 A, E). There is no relation between diamond size and frequency of lamination lines. Although deformation predated resorption there is no evidence for the length of time between processes.

Orlov (1977) suggests that deformation is related to xenolith disaggregation i.e. related to kimberlite eruption. Robinson et al. (1989) advocate that deformation occurs during the same event which forms sheared peridotites. However, diamond has yet to be found in association with such rocks (Otter et al. 1994). According to them it seems possible, that diamond deformation may occur soon after crystallization, possibly due to stresses within the confines of its host rock. McCandless et al. (1994) believe that deformation with graphitization may also be caused by heating associated with stress at the time of conduit formation for the ascending magma.

Robinson et al. (1989) suggested that lamination lines are more commonly developed in brown than in yellow to colorless diamonds. On the other hand, many diamonds with lamination lines are colorless. The stones from the Macaubas River Basin do not show any correlation between brownish color and lamination lines, which suggest (in agreement with McCandless et al. 1994) that some deformation must have taken place prior to conduit formation.

Dissolution produces another type of surface feature in form of triangular pits (trigons) on the octahedral faces, which are oriented anti-parallel to the face configuration. Such trigons could be identified on 16% of Macaubas diamonds (e.g. Fig. 5 A, B). Both types described by Orlov (1977), the pointed

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**Table 2** - Secondary morphology due to resorption of the examined diamonds (the 16.2% of total examined stones and classified as "not identified" are not included).

<table>
<thead>
<tr>
<th>Resorption Category</th>
<th>Percent of examined diamonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>18.4</td>
</tr>
<tr>
<td>4</td>
<td>14.9</td>
</tr>
<tr>
<td>3</td>
<td>12.3</td>
</tr>
<tr>
<td>2</td>
<td>21.9</td>
</tr>
<tr>
<td>1</td>
<td>32.5</td>
</tr>
</tbody>
</table>

**Table 3** - Percent of crystal regularity of examined diamonds.

<table>
<thead>
<tr>
<th>Equidimensional</th>
<th>Intermediate</th>
<th>Distorted</th>
<th>Not identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.5%</td>
<td>14.6%</td>
<td>32.8%</td>
<td>22.1%</td>
</tr>
</tbody>
</table>

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Joachim Karlukkel et al.
trigons and the flat-bottomed trigons have been observed on the examined stones. Pointed trigons often develop in groups whereas the flat-bottomed type are isolated and not connected. Low relief surface features have been observed on 64% of Macaúbas diamonds. They include shagreen texture (e.g. Robinson 1979) and are represented by abundant small hillocks (e.g. Fig. 8 A), which gives the stones a translucent appearance (McCandless et al. 1994), and represent the advanced stages of resorption. Medium to coarse pyramidal, and less common, blocky hillocks occur on 76% of examined diamonds. They are more common on advanced tetrahedral forms. According to Orlov (1977) pyramidal hillocks are formed simultaneously with the curved-faced surface, when the round crystal faces show a specific structure, so that their forms depend on the curvature features of the faces and their relative position on the faces. Although the most frequent form is triangular pyramids, blocky hillocks (which Orlov called quadrangular pyramids) can develop at edges.
Pitted cavities, grooves, rats and hollows are observed on 72% of Macaúbas diamonds. About one quarter of these show well defined large inclusion pits on broken surfaces (e.g. Fig. 8 A, B). Such pits are believed to represent, according to Otter et al. (1994) mineral inclusions that facilitated breakage of the host diamond due to internal strain developed by differential expansion during eruption. Etch channels penetrating deep into the tetrahedral forms have been observed on several Macaúbas diamonds (e.g. Fig. 7 A, B, G, H). Some extensive half-moon-like “perception marks” are seen at higher magnification to be etch features on their internal surfaces, which prove that they are not of sedimentary origin, but represent igneous etch channels (e.g. Fig. 6 B, D). Corrosion sculpture on tetrahedral surfaces which imply, according to Orlov (1977) that corrosion took place only after dissolution, could be observed only on few Macaúbas diamonds.

As to the secondary features of Macaúbas diamonds, 16.2% exhibit percussion marks as described above (e.g. Fig. 6 E, F), a relatively low percentage in comparison with other regions of the Espinhaço Range (e.g. Banko 1997, Chaves 1997). Only 27.2% of the same population show wear on edges and/or apex (e.g. Fig. 5 F, 8 D, F). Some diamonds are of irregular shape with tale-like extensions. Of the cleaved diamonds 22.2% show no etch features. The cleavage and wear of these stones have been considered as of secondary sedimentary origin. For the 3.3% cleaved diamonds without any diagnostic features, SEM-analyses are necessary to confirm their cause.

CHARACTERISTICS OF MACAÚBAS BASIN SEDIMENTS The northeastern part of the Macaúbas River Basin (about 15% of the total basin area) is composed of Mesoproterozoic quartzites with locally metagranulitic lenses of the Espinhaço Supergroup. According to Karfunkel & Karfunkel (1977) these conglomeratic lenses, interpreted as shore deposits could represent the source of the recent diamondiferous gravel of the basin.

Martins et al. (2000) propose that these conglomerates are quite different from the deeply weathered diamondiferous Sopá conglomerates of the Diamantina region. There is no record of any successful exploiting activities in the Espinhaço conglomerates of the Macaúbas Basin and according to experienced diggers they are barren.

The majority of the rock units in the Macaúbas River Basin are composed of glaciogenic metasediments of early Neoproterozoic age of the São Francisco Glaciation. Karfunkel & Karfunkel (1977) recognized three main glacial facies regarding the depositional environment (i) glacial-continental facies (ii) ground-ice facies, and (iii) glaciomarine facies. The Macaúbas River Basin sediments have been interpreted as ground-ice deposits. Martins et al. (2000) demonstrated that thickness of these deposits is in the order of 250-350 m all over the basin area. Many outwash sediments and eskers have been identified (Karfunkel & Karfunkel 1977), locally with slumping features. Eskers are oriented in several directions, but north-west-south-east directions predominate. This is in agreement with Dupont et al. (2000), and Karfunkel et al. (2000) who claim ice-transport directions in the continental facies from NNW towards SSE.

Glacial sediments of the Macaúbas Basin underwent regional metamorphism at the end of Precambrian and exhibit today low to medium greenish facies metamorphic overprint.

Diamictites (sensu Pettijohn 1957) have heterogeneous grain-size distribution and can incorporate granule, gravel, cobble, and boulder of all sizes, composition, angularity and sphericity. Diamictites of glacial origin (tillites) show this features in the examined area, and the largest observed boulder in the tillite of the Macaúbas River Basin has a diameter over 1 m. Grain-size distribution analyses from tillites of the Macaúbas River Basin and from recent gravel have been carried out from several localities. Remarkable is a relatively homogeneous grain-size distribution from different basin samples (tillite and recent gravel). This reflects uniform transport conditions and similar source rock(s) for the glaciogenic and recent sediments in the area. Granule, pebble, cobbles, and boulder counts for 5-10% of the total sediment load (in agreement with Karfunkel et al. 1984) and are of different composition (e.g. quartzites, quartz, granitoid rocks, carbonates). The clay-silt, the very fine sand, and the fine sand fractions make up together about one fifth of the matrix, whereas about two thirds show grain sizes up to 2 mm. The recent gravel is poor in the clay-silt, the very fine sand, and the fine sand fractions.

Very locally Martins et al. (2000) registered remnant Cretaceous conglomerates. In other regions these conglomerates have been interpreted as formed during upheaval of the Espinhaço Range in early Cretaceous time (e.g. Karfunkel & Chaves 1995, Chaves & Karfunkel 1997 ). Precambrian diamondiferous conglomerates have been reworked and distributed to these Phanerozoic sediments. The remnant conglomerates of this epoch in the Macaúbas River Basin are probably not diamondiferous because their Espinhaço source rocks lying in the east, as showed by Martins et al. (2000) are barren. Thus the ultimate primary source of the Macaúbas diamonds remains an enigma.

Recent diamondiferous gravel in the Macaúbas River Basin has been analyzed for mineralogical composition. Garnet (almandine-pyrope), staurolite, Chissoberyl and monazite, identified by X-ray diffraction and Micro-Raman-Probe, are exotic and do not occur in the lower/medium greenish metamorphic facies or other rocks in the Macaúbas River Basin. Yellow-greenish chissoberyl of gem-like quality up to 0.8 cm in diameter and monazite are of pegmatitic origin. Pegmatites, have not been identified during detailed mapping of Martins et al. (2000) in the Macaúbas River Basin. Garnet and staurolite occur many dozens of km to the east of the basin (Costa 1987) and no transport from this region towards the
Macuábas River Basin is known. Thus, source rocks of these minerals could have originated towards the northwest. Transport by ice, as postulated by Gonzaga (personal communication) during the São Francisco Glaciation from their original source towards the actual Macuábas River Basin, in pebbles, cobbles, boulders or even in part of the matrix, is plausible. This is of primary importance for considering the geographic source area of Macuábas River Basin diamonds.

**DISCUSSION**

Most papers dealing with diamond characteristics and their (secondary) deposits discuss in detail either the geology of deposit(s) or concentrate on description of diamonds. However, both aspects are in general linked and should be discussed equally.

The history of Macuábas River Basin diamonds in their ancient and recent sedimentary environments is extremely complex and difficult to interpret. Therefore we tried to couple characteristics of diamonds (primary and secondary), identify heavy minerals occurring in diamodiferous gravel, facies analyses, paleogeography and transport direction studies of glacial sediments.

The Macuábas River Basin show the following peculiarities compared to other diamodiferous areas of the Espinhaço Range in Minas Gerais (i) the majority of its area is composed by glacial sediments of the Macuábas Group (ii) it is (together with the smaller northern lying Congonhas Basin) the only place in the State in which carbonados occur in notable quantities together with diamonds (iii) diamond characteristics are partly different in contrast to those of other diamodiferous fields, and (iv) occurrence of some exotic heavy minerals, which can not genetically be related to the local geology.

The source of Macuábas River Basin diamonds is still debatable, but the combination of data allows to establish a preliminary hypothesis for their origin.

Half of the examined diamonds are cleaved, of which three quarters are attributes to primary processes. This is not consistent with the results obtained by other authors (e.g. Karfunkel et al. 1996, Banko 1997, Chaves 1997, Banko & Karfunkel 2000) for diamonds from the Espinhaço Range in Minas Gerais. These authors postulated that diamonds in the Espinhaço Range underwent natural selection (sensu Sutherland 1982) due to long fluvial transport from a distant source area, evidenced mainly by crystal morphology, crystal state, gem quality and some surface features of secondary origin (Chaves et al. 1998).

On the other hand Haralyi et al. (1991) described a decrease in diamond size along the Jequitinhonha River course associated with sedimentary processes, except when some large tributaries (mainly the Macuábas River) enter the drainage system. Gonzaga & Tompkins (1991) attributed this fact to features of the tributary area sediments, which are of glacial origin, thus advocating that the glacial transport of diamonds played an important role in diamond distribution.

According to the experimental studies of McCandless (1990) minerals are transported in a high-energy fluvial system with less wear when the finer-grained proportion of the gravel is increased. The presence of fine-grained material in the gravel can significantly hinder the wear of the minerals, probably because the fine-grained component cushions these minerals from contact with the clasts by increasing the overall viscosity of the sediment charge. McCandless (1990) emphasize that these effects must be considered when attempting to correlate the wear of xenocryst minerals from stream sediments with the proximity of their source.

The homogeneous grain-size distribution of sediments associated with the diamond characteristics in the Macuábas River Basin is not consistent with the different degrees of wear observed on its diamonds. Therefore a fluvial transport solely can not explain the characteristics of diamonds in the Macuábas River Basin. Local geological features, exotic minerals in heavy concentrates, as well as characteristics of the examined diamonds point towards a glacial contribution to fluvial processes in the redistribution of diamonds, reinforcing Gonzaga & Tompkins (1991) model.

**CONCLUSIONS**

Although diamonds from the Espinhaço Range and their (secondary) deposits have been studied for over 100 years, their primary source rock is, up to date, unknown. The many magmatic cleaved diamonds summing up with the other mentioned preserved primary (magmatic) surface features indicate either a proximal kimberlitic/lamproitic source or a different sedimentary transport mechanism than fluvial. The latter hypothesis is reinforced by the presence of exotic minerals in the basin gravel, as well as the absolute predominance of glacial sediments. Thus, an extra-basinal (outside the actual geographic site of the basin) source for the Macuábas River Basin diamonds transported by ice during Neoproterozoic time is plausible.

The estimated amount of diamonds washed in the last 200 years, the size of the basin, as well as grain-size-distribution in recent and ancient sediments, combined with wear features on diamonds, and the absent of bort (sensu Gaal 1977) are however not consistent with a direct glacial erosion and transport from kimberlitic/lamproitic rocks. It is much more likely that magmatic sources underwent primary decomposition and erosion. Posterior gentle fluvial processes transported and concentrated diamonds prior to the São Francisco Glaciation. This glaciation was responsible for the removal of the diamonds from their source (secondary and primary) by ice and posterior deposition in the (actual) Macuábas River Basin area. A renewed fluvial transport during recent time concentrated the tillite diamonds to their present sites.

The Gonzaga & Tompkins (1991) model for a glacial transport and redistribution of diamonds seems to be reasonable. Nevertheless, glacial transport is not responsible for the concentration of diamonds, but only for their geographic dislocation (and to a certain amount dispersion). It is quite clear that later, mainly fluvial processes reworking these glacial diamodiferous sediments have the capacity of concentrating diamonds. It is important to note that the morphology and surface features indicate a unique source for Macuábas diamonds and that such surface features do not have aspects that are uniquely glaciogenic in nature.

It is still too early to define a geographical area for the primary source rock(s) of the Macuábas River Basin diamonds. Notwithstanding we can postulate that they have been transported by ice from a north-northwestern lying area.

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Figure 5 - SEM microphotographs of diamonds with primary (magmatic) and secondary (sedimentary) cleavages. (A) M151-1, primary cleavage. (B) detail of “A” showing trigons on cleavage proving that the cleavage is of primary origin. Left - trigon with small other trigons on its bottom, right - detail of the left trigon showing a cracked clay cover. (C) M08-1, fragment with secondary cleavage. (D) detail of “C” showing step-like cleavage with wear proving the secondary origin of the cleavage. (E) M06-1, fragment showing cleavage of secondary origin with wear. (F) detail of “E” showing the wear.
Figure 6 - SEM microphotographs of diamonds with pseudo percussion marks and true percussion marks. (A) M1512-1, tetrahedroid crystal with lamination lines, hillocks, sharp edges and hair-like straight or curved "percussion marks". (B) detail of "A" showing that the "percussion marks" are actually deep etch channels. (C) MMG08-1, tetrahedroid crystal with percussion marks. (D) detail of "C" reveals that some percussion marks are actually etch channels and not sedimentary features. (E) MZ31-5, a percussion mark covered with a layer of secondary material, probably clay. (F) detail of "E" showing the cracks in the clayish material.
Figure 7 - SEM microphotographs of diamonds with magmatic dissolution and sedimentary wear. (A) MZ31-12, flat tetrahedroid crystal with “wear” on the upper part. Scale bar is 100 m. (B) detail of “A” reveals that the “wear” is of primary nature due to resorption. Scale bar is 10 m. (C) MZMP2-1, octahedron of resorption category 4. Scale bar is 1000 m. (D) detail of “C” showing no sign of wear. (E) MGRD-1, tetrahedroid of resorption category 2, showing lamination lines and hillocks. Scale bar is 100 m. (F) detail of “E” showing the parallel hillocks. Scale bar is 1 m. (G) MTRH1-4, transition of resorption category 3 with ruts and incision pits on the lower part. Shield-like hillocks. No sign of wear. (H) detail of “G” showing the etch features of the lower part.
Figure 8 - SEM microphotographs of diamonds with inclusion pits and wear. (A) MB01-1, flat tetrahedroid with an inclusion pit on the upper part and a breakage on the lower right side. Shagreen texture. (B) detail of “A” showing that the inclusion pit is covered with a clay layer, but still showing parallel linear closely spaced lamination lines. (C) MB02-1, fragment with some wear (D) detail of “C” showing the breakage. (E) MXX-1, distorted tetrahedroid showing lamination lines, percussion marks and some wear on edges. (F) detail of “E” showing breakage on apex (left side). Scale bar is 10 μm.
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