

PROVENANCE OF HEAVY-MINERALS IN THE PIRANHAS-AÇU RIVER, NORTHEASTERN BRAZIL

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ABSTRACT Clino-amphibole, epidote, garnet, sillimanite, tourmaline, staurolite, andalusite, zircon, rutile, augite, ilmenite, hematite and magnetite are the heavy-minerals recorded in the Piranhas-Açu River. Six assemblages were identified: (i) *Garnet-hornblende-tourmaline* with sillimanite, when cutting rocks of the Seridó Formation; (ii) *Hornblende-garnet-zircon*, when crossing rocks of the Caicó gneiss-migmatite Complex; (iii) *Hornblende-zircon-epidote-staurolite*, when in rocks of the Jucurutu Formation; (iv) *Hornblende-zircon-epidote*, when rocks of the Açu Formation; (v) *Hornblende-zircon-staurolite*, when the lowermost Açu River channel cuts limestones of the Jandaíra Formation, and (vi) *Zircon-tourmaline-staurolite* in the Açu River mouth (Cenozoic rocks) where coastal dynamics dominate. Mineral ratios that reflect differences in grain shape, density, and selective chemical decomposition were used to isolate the effects of "source" and "process" as controls of mineral variability. The reworking of the sediments was regionally effective in selective sorting; the more equant minerals (e.g. epidote) and heavier minerals (e.g. opaques) had a higher probability of being selected for permanent deposition during reworking. The process of selective decomposition dominates at the river mouth.

Keywords: heavy minerals, provenance, Piranhas-Açu River

INTRODUCTION The study of heavy minerals in sediments was established more than 100 years ago and in spite of the general skepticism towards its value during the middle of this century, the technique has not been neglected. Although many studies of heavy minerals are available to the South, Southeast and North of Brazil (e.g. Tomazelli 1978, Villwock *et al.* 1979, Wu and Soares 1974, Wu 1981, Stein 1979, Vital *et al.* 1999), few are found on the Northeast. Moreover, studies of heavy minerals in Northeastern Brazil are concentrated along the coast (e.g. Coutinho and Coimbra 1974) or in the shelf (e.g. Summerhayes *et al.* 1975, Palma 1979). Only now have studies of heavy minerals along a semi-arid northern river from Brazil been published.

The aim of this paper is to characterize the spatial distribution of heavy mineral associations along the Piranhas-Açu River, which drains a semi-arid hinterland and is the main river of the Rio Grande do Norte State (Northeastern Brazil), trace their provenance, define sediment dispersal patterns, and understand sedimentary processes within the channel of a river of a semi-arid climate.

STUDY AREA The study area is situated in the center-northern portion of the State of Rio Grande do Norte, along the Piranhas-Açu river channel, along about 250 km between the city of Parelhas and its to the mouth, in the city of Macau (Fig. 1). The hot and dry or semi-arid tropical climate prevails in the area, with annual average temperature and rainfall about 27°C and 500 mm, respectively. Geomorphologically the study area encompasses the Borborema Plateau, the Sertaneja Depression and the Coastal Plain, as well as alluvial plains, coastal tablelands and the Apodi Plateau.

Most of the hinterland of northeastern Brazil, drained by Piranhas-Açu River, exposes crystalline rocks of a Precambrian Shield (Caicó Complex and Seridó Belt: Jucurutu, Equador and Seridó Formations) intruded by granites. Along the coast, the shield is embayed by the Potiguar Basin where Tertiary (Barreiras Formation) and Quaternary (Alluvial covers) sediment, along with Cretaceous strata, crop out (siliciclastic Açu Formation and carbonatic Jandaíra Formation). Tertiary magmatic rocks also occur (Fig. 1).

MATERIALS AND METHODS Forty-seven sediment samples were collected along the channel and river margins by bottom-grab at intervals between 5-10 km. Positions of sampling sites were obtained by means of a Global Positioning System (GPS).

Grain-size determinations of the sand fraction were carried out by dry sieving at 1 phi interval. Heavy minerals were separated using Bromoform (density 2,89 g/cm³). Analyses were carried out on the 0,125-0,063 mm fraction using a petrographic microscope. This fraction was chosen by its abundance of heavy mineral, as compared to other poorer fractions. Heavy mineral proportions were estimated in this fraction by counting at least 300 translucent detrital grains in each mount using the line counting method described by Mange and Maurer (1992). Methods are detailed by Silva (1999).

RESULTS Heavy mineral characterization Many heavy mineral species were recorded along the Piranhas-Açu River, clinoamphibole, epidote (including zoisite), garnet, sillimanite,

tourmaline, staurolite, andalusite, zircon, rutile, augite, ilmenite, hematite and magnetite. Major transparent minerals, those forming more than 5% of some assemblages, are hornblende, epidote, tourmaline, staurolite and zircon. Ilmenite, hematite and magnetite are the major opaque minerals, ilmenite being by large the most abundant. The bulk of heavy minerals in the analyzed fraction varies between 1% and more than 80%, but in the average 13%.

Heavy mineral distribution The behavior of the heavy minerals along the Piranhas-Açu River is shown in figure 2. The opaque minerals are distributed in significant, yet sporadic amounts along the river. The amount of these minerals increase in the area of the medium course (among 180-150 km) and in the mouth of the river (last 10 km) (Fig. 2).

The distribution of the hornblende, in noticeable amounts along the river, indicates a continuous transport in spite of being an unstable mineral (Fig. 2). The smallest values (below 40%) are found close to the city of Parelhas where the river cuts the aluminous mica schists from the Seridó Formation and locally in the vicinity of São Rafael City and at the mouth of the river.

Epidote is homogeneously distributed along the river, always in inferior amounts up to 5%. Exceptions are observed between 140 and 110 km, close to São Rafael City, where the values oscillate around 10%, but could reach even more than 20% between 90 and 75 km near Açu City. Here, epidote has relatively superior values compared to 5% (Fig. 2). In the first case, the river cuts paragneiss of the Jucurutu Formation and suites of porphyritic and biotite granites. In the second one, it crosses sandstones from the Açu Formation.

The distribution of the zircon presents the smallest amounts close the City of Parelhas and the largest in the river mouth, around Macau City. Oscillations are observed in these two ends, but toward the mouth, an increasing amount is observed (Fig. 2).

The garnet decreases toward the mouth, reaching values larger than 40% near the Parelhas City and practically disappearing in the area of Macau (Fig. 2).

The amount of staurolite oscillates along the river. However, there is a tendency to ascending to the lowermost Açu River, when crossing Jandaíra Formation limestones and Cenozoic rocks (Fig. 2).

The tourmaline presents values greater than 5% around the city of Parelhas and in the lowermost Açu River, where it starts to increase progressively toward the mouth, reaching values about 15%. Between the cities of Caicó and Assu it doesn't surpass the 5% (Fig. 2). The amount of sillimanite is remarkable where the river cuts the aluminous mica schists from Seridó Formation near of Parelhas City, but decreases toward the mouth. The amount of kyanite is small. The andalusite amount oscillates along the river.

Sedimentary processes The presence of heavy minerals in determined studied areas can indicate the mineralogical composition of the source area, but such composition can also be affected by other processes during the sedimentary cycle (Morton 1985) (Fig. 3). Such Processes as: (i) weathering in the area source (previous the incorporation in the transport system), (ii) effects of the transport

process, (iii) hydraulic conditions in the deposition period and (iv) the diagenetic processes that operate after the deposition (Morton and Johnsson 1993). There are no doubts that during the weathering and the processes of soil formation, the mineralogy of the rock bedding can be strongly altered. In theory, the degree for each one of these occurrences in the area source of the sediments essentially depends on the climate and erosion's rate. The combination of these processes can generate heavy mineral suites that are considerably different when compared with those present in the source rock, and sheds doubt on the reconstruction of the provenance.

To understand the role of each one of the processes (weathering, transport, hydraulic conditions, diagenesis), involved in the generation of heavy mineral assemblages, we must try to isolate the effects of "source" and "processes" as controls of mineral variability. It was used mineral ratios, that are comparatively immune to alterations during the sedimentary cycle (e.g. Flores and Shideler 1978, Vital 1996, Vital *et al.* 1999, Silva, 1999).

The influence of sediment- grain size on individual heavy minerals, in response to the hydraulic fractionation (Rittenhouse 1943), is minimized in this study by using a limited size range (Morton 1985, Morton and Hallsworth 1994), the very fine sand fractions (0,063mm - 0,125 mm). Heavy-mineral ratios were used to examine the difference in the grain shape, density and selective chemical decomposition (Flores and Shideler 1978). The shape-fractionation index is expressed by ratios of equant minerals (garnet and epidote) to bladed-elongate minerals (pyroxene + hornblende + tourmaline). The

ratio used in this study is epidote / (hornblende + tourmaline), hereafter referred to as E/HT. Hydraulic fractionation by density is expressed by the ratio of opaque (ave. sp. gr. = 4.7) minerals to non-opaque (ave. sp. gr. = 3.7), hereafter referred to as O/NO. The contribution of selective chemical decomposition to heavy mineral variation is inferred from a stability index (zircon + tourmaline + rutile) / (hornblende), hereafter referred to as ZTR/H.

The analyses of these mineral ratios (Fig. 2) show that the selective decomposition (mineral stability), suitable for the index ZTR/H, did not play a significant role in the variation of heavy minerals along the river. This suggests that the process of selective decomposition has acted uniformly along the river. However, at the river mouth, where the coastal processes are active, the selective decomposition is more outstanding. In contrast, limited effects of hydraulic fractionation are observed along the entire river. Hydraulic fractionation largely by shape is suggested by E/HT ratios, which presents significant differences, mainly between 140 and 100 km (Fig. 2). In the same way, along the river, there is a contribution of the hydraulic fractionation by density (O/NO). Although significant differences in the E/HT and O/NO ratios along the river suggest effects of differentiation in the hydraulic fractionation, these differences could also be induced by a provenance factor.

CONCLUSIONS One of the most important aspects of this study is that the mineralogy of the source rocks are comparatively well known. So, the analysis of the heavy mineral distribution along the

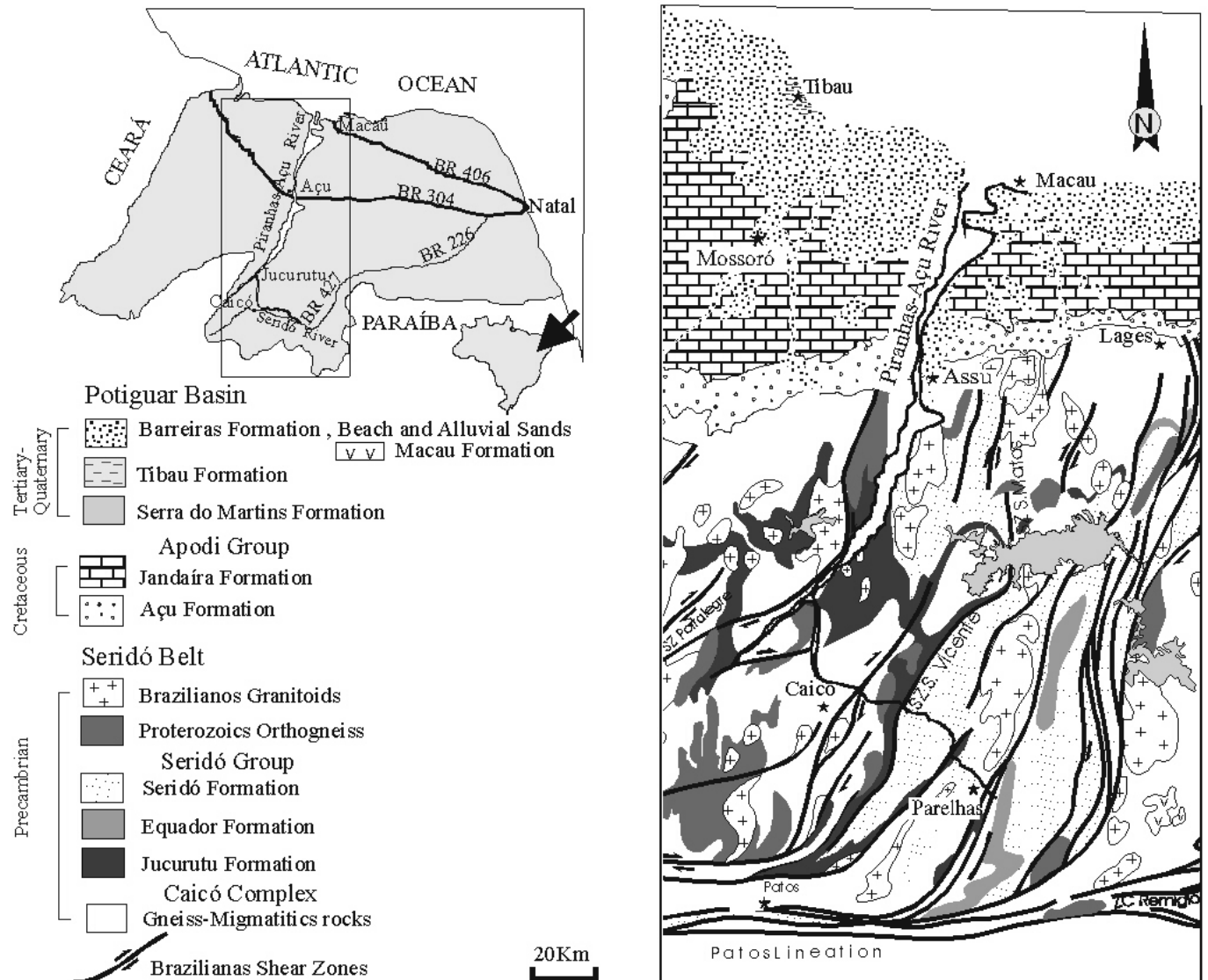


Figure 1 - Location of the Piranhas-Açu River and geologic map of the study area (simplified from Menezes 1999).

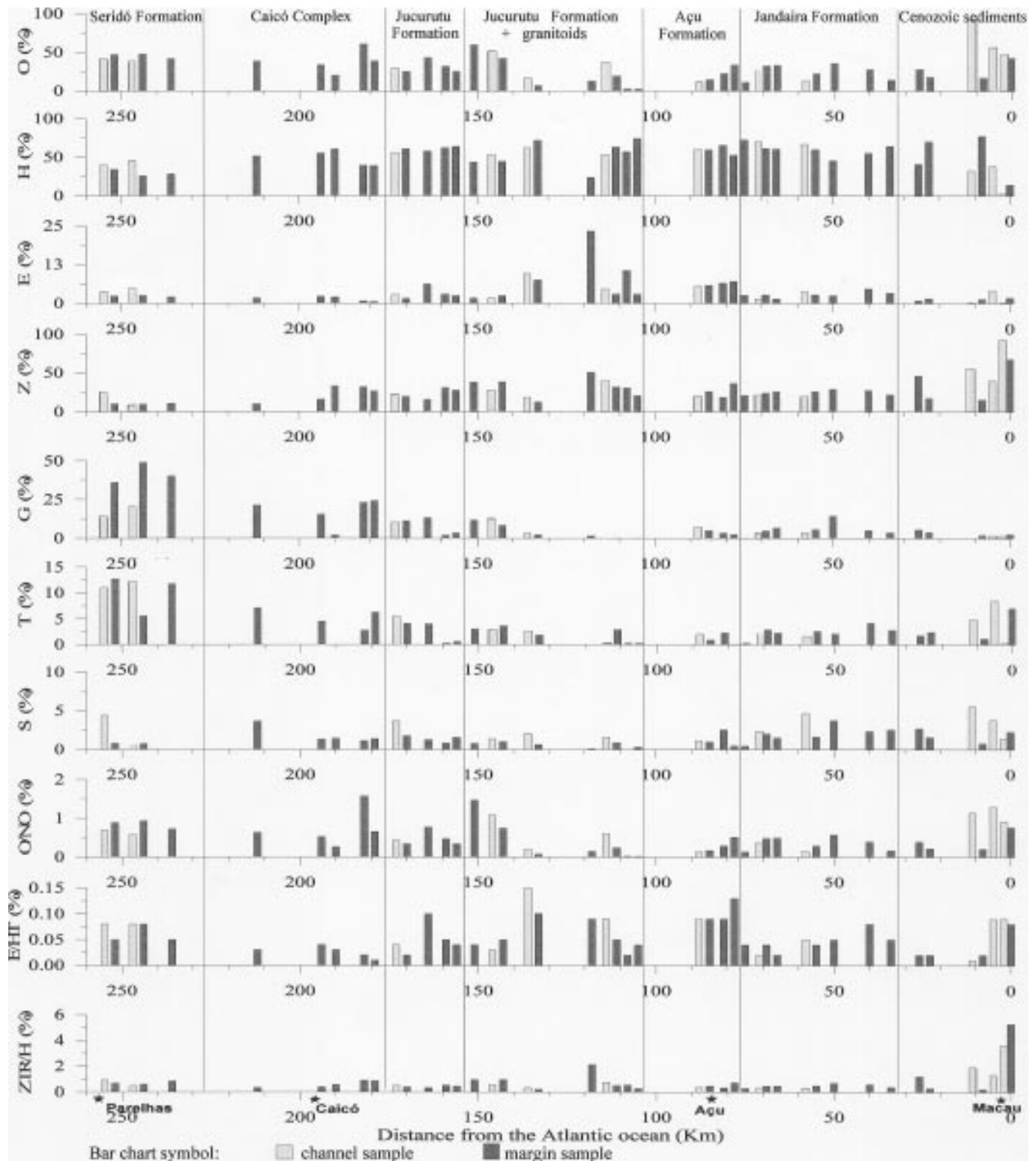


Figure 2 - Major heavy mineral variations along Piranhas-Açu River. O = opakes; H = hornblende; E = epidote; Z = zircon; G = garnet; T = tourmaline; S = staurolite; NO = non-opakes, HT = hornblende + tourmaline, ZTR = zircon + tourmaline + rutile.

Piranhas-Açu River, associated with previously known information concerning the mineralogy of the crossed units for this river, yielded an understanding in the distinction of six assemblages of heavy minerals as follows:

- (i) *Garnet-hornblende-tourmaline with sillimanite*, when cutting rocks of the Seridó Formation (aluminous mica schists, with variable percentages of garnet, cordierite, staurolite, sillimanite, andalusite and rarely kyanite). This area is near the Queimada

Hill (Equador Formation constituted by quartzites with muscovite, tourmaline \pm sillimanite, and locally rich in epidote \pm garnet).

- (ii) *Hornblende-garnet-zircon* when crossing rocks of the Caicó gneiss-migmatite Complex (predominance of tonalitic to granodioritic orthogneisses, and calc-alkaline or subalkaline/monzonitic granites).

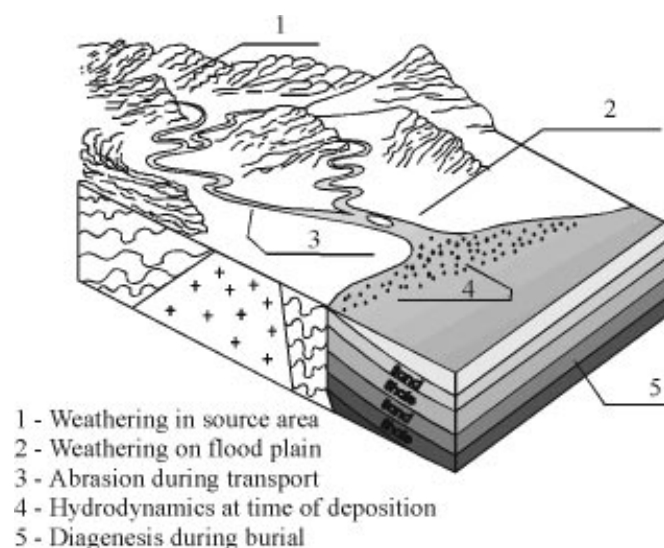


Figure 3 - Schematic illustration of the processes that operate during the sedimentary cycle to overprint the mineralogical signature of the source rocks (modified from Morton 1985).

- (iii) *Hornblende-zircon-epidote-staurolite* when the river cuts the Jucurutu Formation (paragneiss with biotite \pm epidote \pm diopside \pm amphibole. With frequent intercalations of marbles, calcsilicate rocks and paramphibolites), with lateral influence of granites intrusions (biotite-granites, peraluminous or subaluminous, and calc-alkaline suites).
- (iv) *Hornblende-zircon-epidote-staurolite*, when the river crosses the Açu Formation (alluvial sandstones, conglomerates and claystones and fluvial to shallow marine sandstones and claystones).
- (v) *Hornblende-zircon-staurolite* on the lowermost Piranhas-Açu River, when crossing limestones from Jandaira Formation and sediments of the Cenozoic rocks.

Table 1 – Heavy minerals and probable source rocks.

| HEAVY MINERAL | MOST PROBABLE SOURCE |
|---------------------------------|---|
| Hornblende | Micaschists of the Seridó Formation, orthogneiss and amphibolites of the Caicó Complex, paragneisses and paramphibolites of the Jucurutu Formation and granite intrusions |
| Epidote | Paragneiss and calcsilicate rocks of the Jucurutu Formation, granite intrusions, gravel deposits of the Açu river and Açu Formation. |
| Sillimanite, Garnet | Micaschists of the Seridó Formation, quartzites of the Equador Formation |
| Andalusite, Kyanite, Staurolite | Micaschists of the Seridó Formation |
| Tourmaline | Micaschists of the Seridó Formation and quartzites of the Equador Formation (prismatic), sediments and sedimentary rocks (round) |
| Zircon | Rocks of the Precambrian Shield in general (pink and prismatic zircon), sediments and sedimentary rocks (round zircon) |
| Opaque minerals | All rocks within the Piranhas-Açu River channel |
| Rutile | Seridó Formation and Caicó Complex |
| Augite | Macau, Cuó and Ceará-Mirim Volcanism |

- (vi) *Zircon-tourmaline-staurolite* in the Açu River mouth (Cenozoic rocks) where coastal processes dominate.

These results allow us to associate each heavy mineral with its most probable source rocks (Table 1).

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