STRATIGRAPHIC SIGNIFICANCE OF HEAVY MINERALS IN SEDIMENTS OF THE NORTHEASTERN BRAZIL

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ABSTRACT Sediments from the Upper Cretaceous post-rift section of Potiguar Basin and their Cenozoic continental covers show that their heavy mineral associations can distinguish stratigraphic units. The Açu River flows along the axis of the basin trough, and its deltaic plain is developed in the coastal region of Macau within the main axis of the basin. The oldest outcropping units are the siliciclastic rocks of the Açu Formation (Albian-Cenomanian) and carbonates from the Jandaíra Formation (Turonian-Early Campanian). Oligocene to Miocene volcanism constitutes the Macau Formation. Miocene fluvial and alluvial fan deposits of the Barreiras Formation and Quaternary fluvial and marine deposits synthesize the continental sedimentation in the basin. Different assemblages have been observed for each siliciclastic unit, with the heavy mineral suites become increasingly complex from the oldest (Açu Formation) to the youngest one, probably reflecting the tectonic events and the erosion history of the source terranes: i) the assemblage from Açu Formation shows almost no transparent minerals (average of 10%) and the texture of opaque grains is intensely corroded; ii) Barreiras Formation are rich in zircon (up to 40%), both prismatic and rounded, and small amounts of epidote, rutile, tourmaline and garnet; iii) gravel deposits are rich in epidote with subordinate amounts of zircon, tourmaline and hornblende; iv) recent alluvial deposits show an increase in the amount of unstable heavy minerals, chiefly amphibole, reflecting a continuos sediment transport from the basement source. The difference in heavy mineral suites from Barreiras Formation and the gravel deposits provides a mean to separate one unit from the other.

Keywords: Heavy minerals, Gravel deposits, Barreiras Formation, Potiguar Basin.

INTRODUCTION Lithostratigraphic units are commonly associated with a particular heavy mineral assemblage. Depositional breaks or unconformities are often characterized by marked changes in the heavy mineral suites. Many studies have applied heavy mineral analyses to define stratigraphic units, as well as stratigraphic correlation (*e.g*. Tieh 1973; Stattegger 1976; Weissbroad and Nachmias 1986).

The Potiguar basin contains reserves of 324 million barrels of recoverable oil and 370 billion cubic feet of gas in place. Many studies have been done because of the economic importance of this find. However, little attention has been given to their sedimentary covers. For example, gravel deposits occurring mainly along Açu River and other important rivers of the region (e.g. Ceará Mirim and Potengi rivers) are thought to be related (e.g. CPRM 1978) or not related (e.g. DNPM 1998) with the Barreiras Formation for no really consistent reason. In order to fill this gap we try to characterize the following units: gravel deposits, Barreiras Formation, through Açu Formation and recent alluvial deposits (active channels and abandoned meanders) through heavy mineral analyses.

STUDY AREA The study area is located in the center-south portion of the Potiguar Basin, on the lowermost Açu River (Figure 1).

The Potiguar Basin is located in Northeastern Brazil. The terrestrial portion of the basin is trough-shaped, limited by NE-SW faults. The offshore portion is limited by E-W and NW-SE faults that form the boundaries of a homocline dipping toward the ocean. The Açu River flows along the axis of the basin trough, and its deltaic plain is developed in the coastal region of Macau within the main axis of the basin. The oldest outcropping units are siliciclastic tocks of the Açu Formation (Albian-Cenomanian) and carbonates from the Jandaíra Formation (Turonian-Early Campanian). Oligocene to Miocene volcanism constitutes the Macau Formation. Miocene fluvial and alluvial fan deposits of the Barreiras Formation and Quaternary fluvial and marine deposits synthesize the continental sedimentation in the basin (Figure 1).

Fonseca (1996) investigated the morpho-sculpture and morpho-structure in the lowermost Açu River (RN), establishing five morphotectonic blocks. In some cases, these compartments provide useful markers of the neotectonic activity of the region. The characterization of the gravel deposits studied in this work contributes to the temporal placement of the observed structures.

The siliciclastic units analyzed in this study are briefly described as follows:

The Açu Formation comprises a basal section, formed by a thick interval of alluvial sandstones, conglomerates and claystones. The uppermost part, is a thin layer of fluvial to shallow-marine sandstones and claystones.

The siliciclastic rocks correlated to Barreiras Formation are sands, muddy-sands or conglomerate deposits of variable color (yellow, red, and white). They may be massive, or show cross- or plane-parallel bedding. Cliffs of the Barreiras Formation crop out on the coast.

Gravel deposits are constituted of conglomerates with dispersed pebbles in a coarse sand to clay matrix. The pebbles are essentially composed by quartz, silex and rock fragments; they show wide variation in roundness, sphericity, and grain-size (millimetric to decimetric).

The alluvial sediments occur throughout the area along the Açu River. They form a wide flood plain of muddy composition, as well as fine to coarse sands.

METHODS Samples were taken from cross profiles along the Açu River, in abandoned meanders, outcrops of the Açu and Barreiras Formation and from gravel deposits.

The samples were washed, dried and sieved at 1 ϕ intervals down to 4 ϕ (0,062 mm) for calculation of grain size parameters. Heavy mineral separations were carried out on the very fine (3-4 ϕ) fraction (which we will refer to as “ideal fraction”) of each sample. A total of 45 samples were analyzed.

This “ideal fraction” was obtained based on the analysis of the following grain-size fractions: 0,50-0,250; 0,250-0,125 and 0,125-0,062 mm in representative samples. The very fine sand fraction (0,125-0,062mm) was chosen because it showed the greatest abundance and diversity of heavy minerals.

Bromoform ($CHBr_3$) was used as heavy liquid for mineral separation. Optical analyses of the very fine fractions were undertaken, with mineral proportions estimated by counting a minimum of 300 non-opaque grains, using the ribbon method (Galehouse 1971). Data were tabulated, integrated and analyzed using Excel and Stratgraphics plus software.

RESULTS AND DISCUSSIONS **Heavy mineral characterization** Heavy minerals in the very fine sand fraction range from a maximum of 30% to a minimum of 0.5%. Figure 2 shows the percent averages for each heavy mineral for the 5 units analyzed: Açu Formation, Barreiras Formation, gravel deposits, alluvial sediments and abandoned meanders.

The most abundant heavy minerals in the sandstones of the Açu Formation are opaques (97 %), some of which appear to be strongly corroded (figure 3a). The translucent minerals (3%) comprise zircon (37%), generally prismatic; epidote (38%), mostly irregular with pleochroism varying in shades of yellow; rutile (8%) showing intense red color; green and brown hornblende (6%); yellowish staurolite (6%); and accessory proportions of garnet and tourmaline. The ZTR (zircon + tourmaline + rutile) index for this unit is 45%.

The Barreiras Formation is characterized by the following assemblage of heavy minerals: opaque (49 %). The translucent minerals (51%) comprise zircon (77%), epidote (20%) and rutile (accessory) (Figure 3b). The ZTR index for this group is 80%.

The gravel deposits contain opaques (70 %). The translucent minerals (30%) comprises epidote (68%), zircon (20%), hornblende (4%); tourmaline, rutile and sillimanite (accessory), the ZTR index for this unit is 45%. (Figure 3c).

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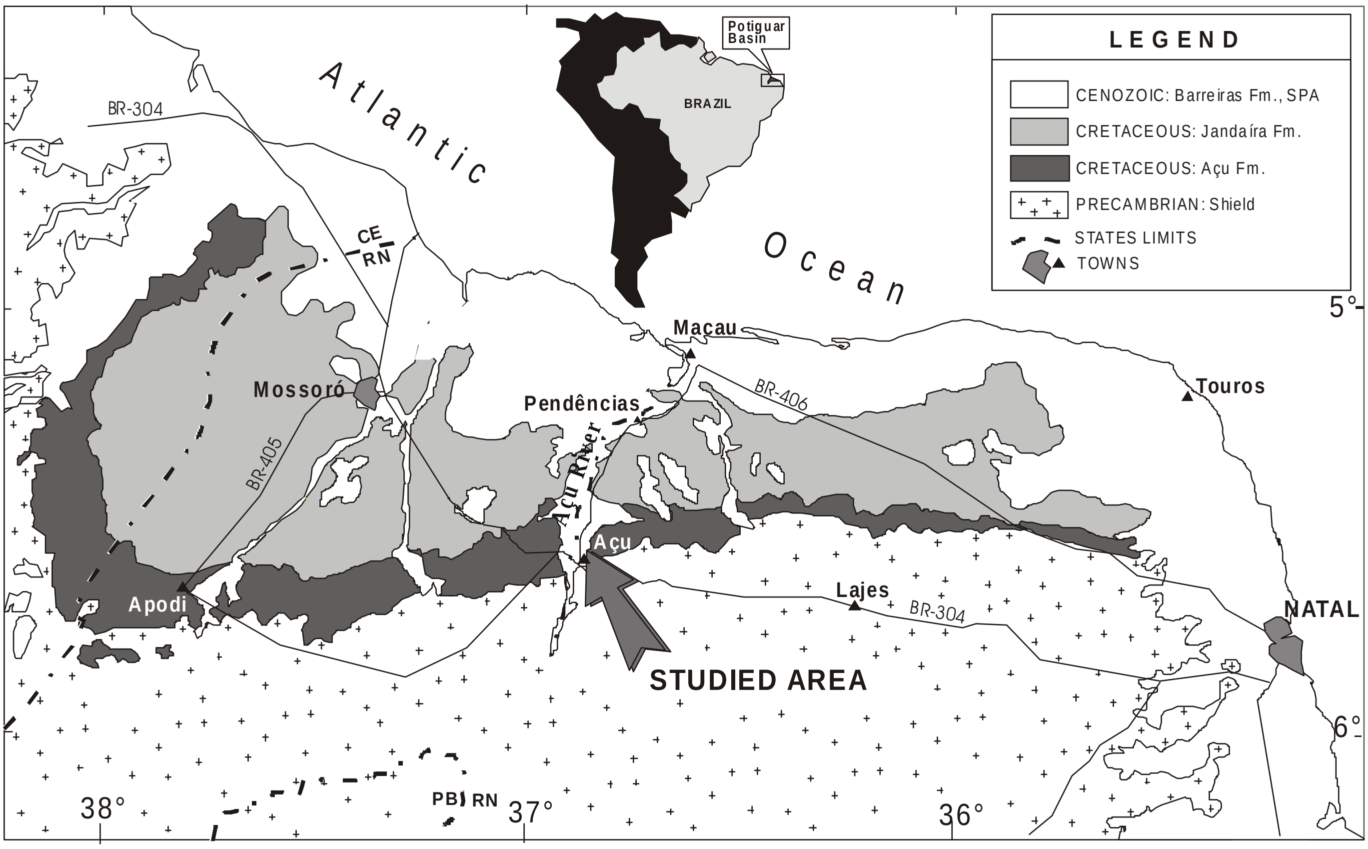

Figure 1 - Geographical and geological map.

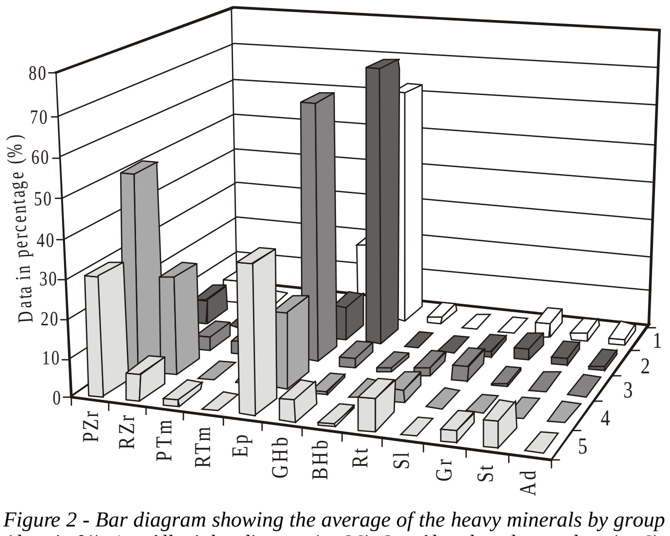

Figure 2 - Bar diagram showing the average of the heavy minerals by group (data in %). 1 = Alluvial sediments (n=26), 2 = Abandoned meanders (n=6), 3 = Gravel deposits (n=7), 4 = Barreiras Formation (n=2), Açu Formation (n=4), n = numbers of analyses. PZr = prismatic zircon, RZr = round zircon, PTm = prismatic tourmaline, RTm = round tourmaline, Ep = epidote, GHb = green hornblende, BHb = brown hornblende, Rt = rutile, Sl = sillimanite, Gr = garnet, St = staurolite, Ad = andalusite.

A greater diversity of translucent (80%) heavy minerals was identified on the alluvium sediments (Figure 03d): hornblende (65%), epidote (20%), zircon (6%); garnet, tourmaline, staurolite and andalusite (accessory). ZTR index is 8% and opaques amounts 20 %. In the abandoned meanders the mineralogy is similar to that in the alluvium, although with a larger proportion of hornblende (73%) and smaller proportion of epidote (9%); ZTR index for this unit is 11%.

Discriminant Analysis Although visual inspection of the diagrams, showed the more obvious trends, the less marked differences could have been easily overlooked. Therefore, employment of advanced numeral techniques was considerably important if the assessment of data was to be objective. Of the large number of statistical methods available, discriminatory analysis was used here.

A total of 45 samples from all five units (Açu, Barreiras, gravel deposits, alluvial sediments, abandoned meanders) were used in the statistical evaluation. Twelve heavy-mineral variables were determined for each sample: 1) prismatic zircon, 2) rounded zircon, 3) prismatic tourmaline, 4) rounded tourmaline, 5) epidote, 6) green hornblende, 7) brown hornblende, 8) rutile, 9) sillimanite, 10) garnet, 11) staurolite and 12) andalusite.

The Stepwise Regression Method (forward selection, F-to-enter) shows that the epidote and rounded zircon are the most effective variables for the separation in groups. The variables sillimanite, rutile, staurolite, prismatic tourmaline, green hornblende, garnet and round tourmaline are partially useful discriminators and contribute to ideal group separation, which account for 100% of the correctly classified samples. The model does not use prismatic zircon, brown hornblende and andalusite.

High canonical correlation and low Wilk's l values suggest that, of the four discriminant functions, the first two are potentially useful discriminators. They also account for 90% of the variance. A plot of the first two discriminant functions yields excellent grouping within and among the five units (Figure 4).

Figure 4 shows that the samples of the abandoned meanders are plotted in the same alignment of the alluvium sediment samples; the samples of gravel deposits and Barreiras Formation are plotted in opposite positions with the Açu Formation clearly in the middle, implying differences in and among these units. These results indicate that the Barreiras and gravel deposit units cannot be considered a single unit. Moreover, the high ZTR index for the Barreiras Formation shows a more mature caricature of these sediments.

SUMMARY AND CONCLUSIONS Heavy minerals have been used in this study for characterization and distinction of stratigraphic

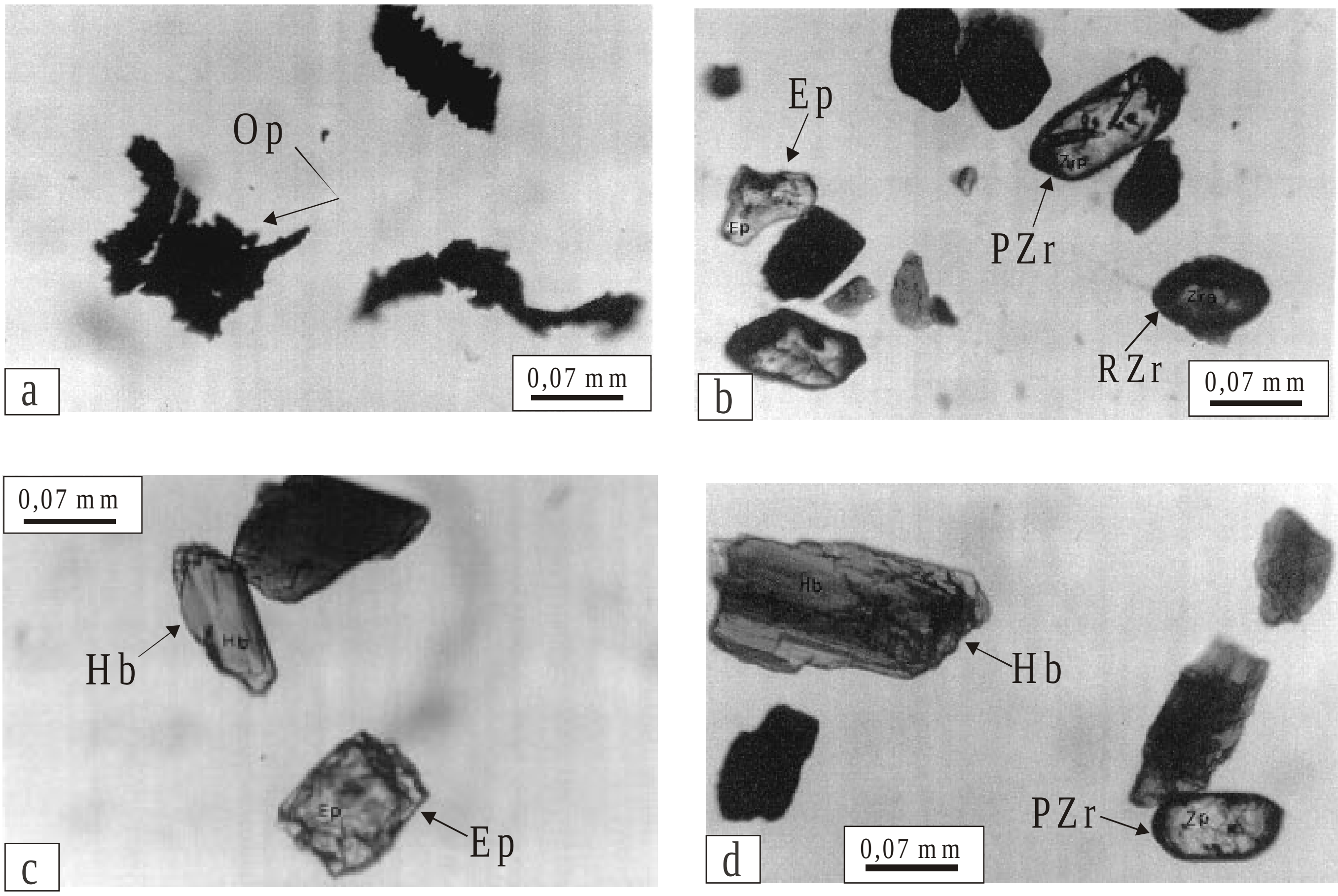

Figure 3 - (a) Corroded opaque from the sandstones correlated to the Açu Formation; (b) Opaque, prismatic (PZr) and rounded (RZr) zircon, and epidote (Ep) of Barreiras Formation sediments; (c) Hornblende (Hb) and epidote (Ep) found in the matrix of the gravel deposits; and (d) Hornblende (Hb), prismatic zircon (PZr) and opaque of the sands found in the profiles of the alluvial sediments. All the fotomicrographs were made with parallel nicols and of 100x magnification.

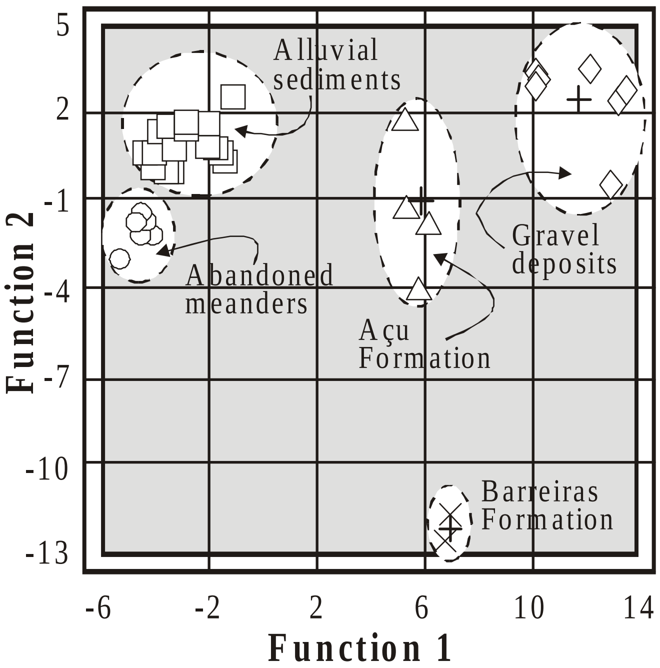

Figure 4 - Discriminant function graphic. ( ) = Alluvial sediments (n=26), (○) = Abandoned meanders (n=6), (×) Formation Barreiras (n=2), (◊) Gravel deposits (n=7), (Δ) Açu Formation (n=4), (+) center, n = numbers of analyses.

units. Our results show that the sediments of the upper Cretaceous section of the Potiguar Basin and its cover (continental Cenozoic) can be clearly classified by its particular heavy minerals associations.

For each unit, different suites were observed. The youngest units have more complex suites when compared to the older ones, probably reflecting tectonic events and the erosional history of the source areas:

(1) Açu Formation is characterized by nearly total absence of translucent minerals (average of 10%) and intensely corroded texture of the opaque grains;

(2) The Barreiras Formation is clearly enriched in zircon, both prismatic and rounded, as well as small amounts of epidote. Rutile, tourmaline and garnet are also present;

(3) the gravel deposits are rich in epidote and contain small amounts of zircon (dominantly prismatics), tourmaline, andalusite and hornblende.

(4) the recent alluvium deposits, as well as the

(5) abandoned meanders show an increase in the amount of unstable heavy minerals, mainly amphibole, reflecting a continuous sediment transport from the shield.

These data demonstrate the value of heavy mineral analysis, as a sensitive indicator of different lithostratigraphic units. The presence of very stable minerals in sediments from Barreiras Formation contrasts strongly with the unstable minerals found in the heavy mineral suite of the gravel deposits. This observation allows their characterization as distinct units. Moreover, this increase in the amount of unstable heavy minerals in the gravel deposits suggests that the gravel deposits are younger than the deposits from the Barreiras Formation.

The distinction between the Barreiras Formation and gravel deposits is reinforced by discriminant analysis, which plots these units in opposite positions. Sediments from abandoned meanders plotted in the same alignment could indicate a possible migration from west to east of the alluvium sediments.

The heavy mineral assemblage from Açu Formation and alluvium sediments from Açu River is essentially the same. The difference is mainly in the relative proportions: stable minerals are more abundant in the Açu Formation, while the unstable minerals dominate in the alluvium sediments. The absence of significant compositional differences resulting from selective chemical dissolution in the sandstones from Açu Formation probably reflects uniform weathering conditions.

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