MORPHOMETRIC ANALYSIS APPLIED TO THE DETECTION OF NEOTECTONIC INFLUENCES IN THE UPPER COURSE OF THE PAPOCAS RIVER BASIN, SOUTH COAST OF PARAÍBA STATE, NORTHEAST OF BRAZIL

Jean Carlos Ferreira De Lima[1], *Gilvonete Maria Araujo De Freitas*[1], *Maria Emanuella Firmino Barbosa*[1, 2], *Marquilene Da Silva Santos*[1] *Saulo Roberto De Oliveira Vital*[1], *Max Furrier*[1]

[1]*Universidade Federal da Paraíba (UFPB);* [2]*Instituto Federal de Educação, Ciência e Tecnologia do Estado da Paraíba (IFPB), Departamento de Geociências, CCEN/UFPB, 58059-900 - João Pessoa (PB)*

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Abstract

To detect resurgent tectonics in river basins, the morphometric analysis of the drainage network starting from the use of stream-gradient index (slope x length) becomes an important resource to confirm or refute the preliminary hypotheses about the integration of tectonic and depositional processes, enabling the identification of possible relief responses to recent tectonic changes. The study area corresponds to the upper course of the Papocas river's basin. This basin is located on the south coast of Paraiba State in northeastern Brazil, and was chosen because it presents some peculiarities, such as some of its tributaries having inflected forms and its flows a high power of holding the carving of the substrate, suggesting a structural and strong control, possibly caused by reactivation of tectonic fault systems in existing fragile areas. The results achieved demonstrated the presence of clear anomalies of course caused by uplift and/or subsidence of sedimentary packages. Such anomalies are usually detected before the 2000 m toward the source of each tributary, suggesting that the entire area around the upper course of Papocas river's basin is undergoing a process of dynamic adjustment, resulting from neotectonic movement reflected in the geomorphology of the area.

Keywords: *Morphometric analysis, Neotectonics movements, Papocas river.*

Resumen

Para la detección de la tectónica de resurgimiento en las cuencas hidrográficas, el análisis morfométrica de la red de drenaje por el uso de lo índice RDE se convierte en un recurso importante para confirmar ou refutar las hipótesis preliminares acerca de la integración de los procesos tectónicos y sedimentación, lo que permite la identificación de las posibles respuestas a los últimos cambios tectónicos em las formas terrestres. El área de estudio corresponde a la parte alta de la cuenca del rio Papocas. Esta cuenca se encuentra em la costa Sur del estado de Paraíba, en el Noreste de Brasil, y fue elegida debido a que presenta algunas particularidades, como algunos de sus afluentes con fuertes inflexiones y los flujos de una capacidad de alta talla del substrato, lo que sugiere um fuerte control estructural, posiblemente causado por la reactivación de los sistemas de fallas tectónicas en las zonas frágiles. Los resultados mostraron la presencia de anomalías agudas causadas por la elevación en curso y/o hundimiento de los paquetes sedimentarios. Esas anomalías se detectaron geralmente antes de los 2000 m hacia la fuente de cada tributário, lo que sugiere que toda la área alrededor de la parte alta de la cuenca del rio Papocas está experimentando um proceso de ajuste dinámico resultante de la manipulación neotectónica refleja en la geomorfología de la zona.

Palabras clave: *análisis morfométric, movimientos tectónicos, río Papocas*

1. INTRODUCTION

Tectonic movements, probably occurred between the Plio-Pleistocene and Holocene, have clearly had an effect on the modeling of the relief of most of the eastern edge of the Brazilian Northeast. These endogenetic processes influence more intensely the morphological settings of this region's sedimentary coastal landscapes due to its sensitivity to acquire new shapes and greater tendency to an adjustment of geodynamic character, conditioned by plate tectonics.

Many of the study results on the sedimentary formations and structures of the crystalline basement (Bezerra *et al*., 2001 and 2008, Villwock *et al*. 1995; Furrier, 2007, Brito Neves *et al*., 2004 and 2009) have shown that the eastern portion of Brazilian Northeast has undergone a complex evolutionary history, marked by the action of different, slow and continuous morphodynamic processes over long periods of time, and that they are not completely terminated.

The area that corresponds to this study presents strong evidence of the occurrence of recent tectonic activities as sudden inflections in some of their courses, as well as in its vicinities, such as the presence of graben and horst forms and elevations in the form of domes, having a notable influence on the accommodation of several river basins.

Because they are very likely to accommodate to the minimum occurred changes in the lithological structure through which they pass, the water courses serve as guides for the detection of recent tectonic activities. Thus, the analysis of longitudinal profiles followed by morphometric study using the course's Declivity versus Stream Length technique becomes useful for the detection of neotectonic deformations in watersheds.

Morphometric techniques that exploit attributes related to the profiles or to the tracing of the watercourses present a relatively high potential for the detection and evaluation of deformations (Etchebehere et al., 2004). Currently, studies that examine possible responses to tectonic changes in watersheds that have occurred recently have been using as a method of analysis the Declivity versus Stream Length index - RDE, also known as Hack's index.

Hack (1973) proposed the use of such morphometric index as a very practical element for the determination of "anomalies", significant in the natural concavity of the longitudinal profile, which allowed the normalization of the gradient values and the identification of drainage anomalies in each section of course.

In order to characterize and examine the heterogeneous areas within the watershed in analysis, the morphometric index developed by Hack (op. cit), in this case, the Declivity versus Stream Length index - channel Extension - RDE was applied to outline the Longitudinal Profile of the drainages of the upper course of Papocas river's watershed.

2. LOCALIZATION AND CHARACTERIZATION OF THE STUDY AREA

The upper course of Papocas river's basin (Figure 1) is inserted into a portion of the municipal territory of Pedras de Fogo, located in the micro-region of the south coast of Paraíba. Only one of its tributaries has popular denomination, which is riacho dos Marinhos, while the others are designated by numerical references in this paper.

Geological context - The study area is inserted in the eastern portion of Borborema Province, in the morphoestrutural domain of the sedimentary deposits of Pernambuco/Paraíba Sedimentary Basin, specifically in the "Sub-Basin of Alhandra" (Barbosa, 2004), with the crystalline precambian basement, composed of granitoids of indiscriminate chemism, completely covered by platform-residual sediments of the Beberibe Formation, "which rests in a discordant way on the basement" (Mabesoone & Alheiros, 1988) of the Barreiras Group and by colluvial/alluvial post-Barreiras sediments.

According to Brasil (2002), the orogeny of the Brasiliano Cycle occurred in the Borborema Province area printed in the region an elaborate system of shear zones. The study area is just about the division of two different nappes: Alto Moxotó Terrain (TAM) and Rio Capibaribe Terrain (TRC).

The existence of an lineament, known as Congo-Coxixola, needs to be highlighted by presenting complex geometry of en echelon faults, that were reactivate during the evolution of the Sub-basin of Alhandra, with significant, overall and structural impact (Brito Neves *et al*. 2009). This can influence in a prominent way the arrangement of the drainage network and the configuration of the regional relief, consequently in the study area.

According to Bittencourt *et al*. (1999), reactivations of older faults and generation of new faults produced by flexural deformation of the lithosphere occur due to sediment load deposited on the continental margin and constant movement in the South American platform. "The vast majority of them presents reactivation since before the Tertiary to Quaternary, pre-existing weak zones in the structure of the basement" (BEZERRA *et al.*, 2001).

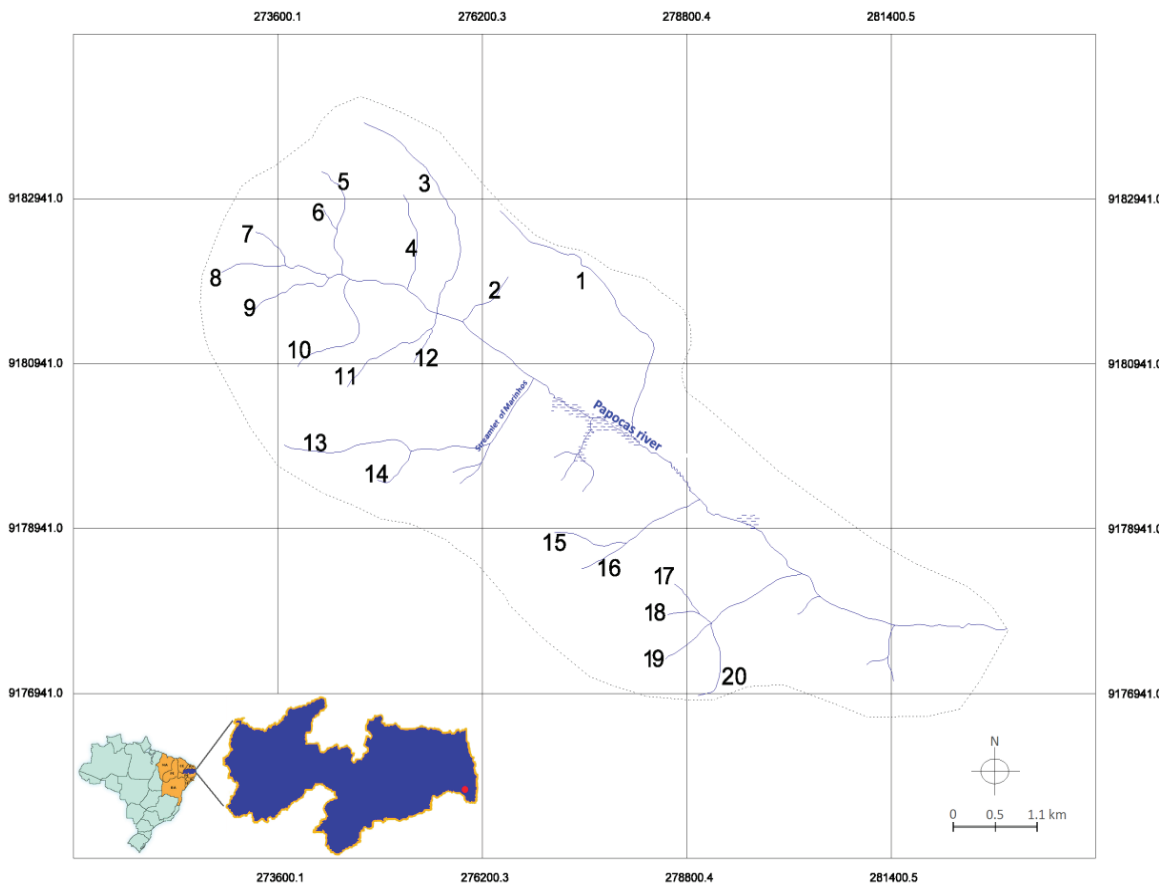

Figure 1. Location of the study area.

Geomorphological context - The upper course of the river basin Papocas is inserted in the Geoenvironmental Unit of the Sub-littoral Coastal Tablelands, and its relief generally involves plateaus of sedimentary origin that present variable degrees of carving, sometimes with narrow valleys and abrupt slopes, other times with gentle slopes and open funds with broad floodplains. These trays have flat or slightly wavy and gently inclined to the east tops, always carved by the channels of the drainage network.

According to Resolution nº 303 of 20.03.2002 (Article 2, section XI) of National Environmental Council (CONAMA, 2002), tableland is a landscape of flat topography, with an average slope of less than ten percent, approximately six degrees, area of more than ten hectares, ended abruptly in scarp. This geomorphological domain constitutes a semi-tabular subestructural surface with dip in the NE-E that extends from north to south around the coast of Paraíba.

3. TECHNICAL AND OPERATIONAL PROCEDURES

The technical and operational procedures consisted initially in the selection of references on the use of the waterways' morphometric analysis techniques and on the geological and geomorphological conditions of the study area. Then software SPRING 5.1.7 was used to delimit the drainage network of the upper course of Papocas river's watershed, generated from the contours, with equidistance of 10 m, taken from the topographic chart Pedras de Fogo (SB.25-YC-II-4-SE), linkage compatible with the scale 1:25.000, with the purpose of calculating the Declivity versus Stream Length (RDE) of its tributaries.

In this work, the calculation of RDE (Declivity versus Stream Length) was conducted based on the full extent of each tributary (RDE_{total}), understood from its headwaters to the junction with the main river.

As this work is considering the possibility of neotectonic influences on the relief's modeling, subsidies to achieve more consistent results on these hypotheses are searched on the methodology developed by Burnett & Schumm (1983). Such technique exists based on the concept that the rivers that drain into areas under neotectonic influence are constantly adjusting their course to the changes of slope.

Thus, the authors propose a new interpretation to the construction technique of longitudinal profiles of valleys where there is an overlap of the longitudinal profile to its Line of Best Fit. This allows determining more clearly the areas in the process of subsidence and/or uplift (Figure 2).

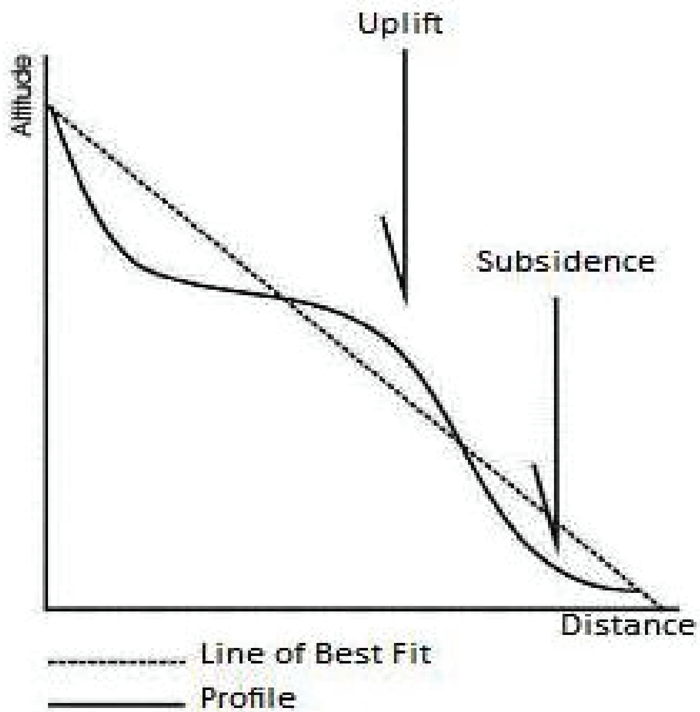

Figure 2. Hipothetical model of the longitudinal profile, plus the Line of Best Fit proposed by Burnett & Schumm (1983).

According to Knighton (1998), the longitudinal profile is a simple and effective method, which basically makes use of altitude data and length of the canal, to generate an upward concave logarithmic adjustment curve, which has higher slopes in headwaters and lower slopes toward the mouth, being so the characteristic graphical representation of rivers in a state of equilibrium.

According to Etchebehere et al. (2004), the RDE index can be calculated as follows: **RDE = (Δh/Δl). L**

Where Δh is the difference in height between two extreme points of a segment along the watercourse; Δl is the horizontal projection of that segment's extension's length (i.e., Δh/Δl corresponds to the gradient of the drainage in that segment), and L corresponds to the total length of the watercourse upstream of the point to which the RDE index (Declivity *versus* Stream Length) is being calculated.

4. RESULTS

The results achieved with the use of longitudinal profiles, enhanced with the Line of Best Fit on some tributaries that showed sharp anomalies of course, demonstrated that they are influenced by tectonic uplift and/or subsidence.

The graphs below show the courses that had rates of well above average overall (64,21). The calculation was made based on the total drainage of the tributaries, except the main course, which had only the segment corresponding to its study area analyzed ($RDE_{segment}$) (Figure 4). The results are shown in Table 1

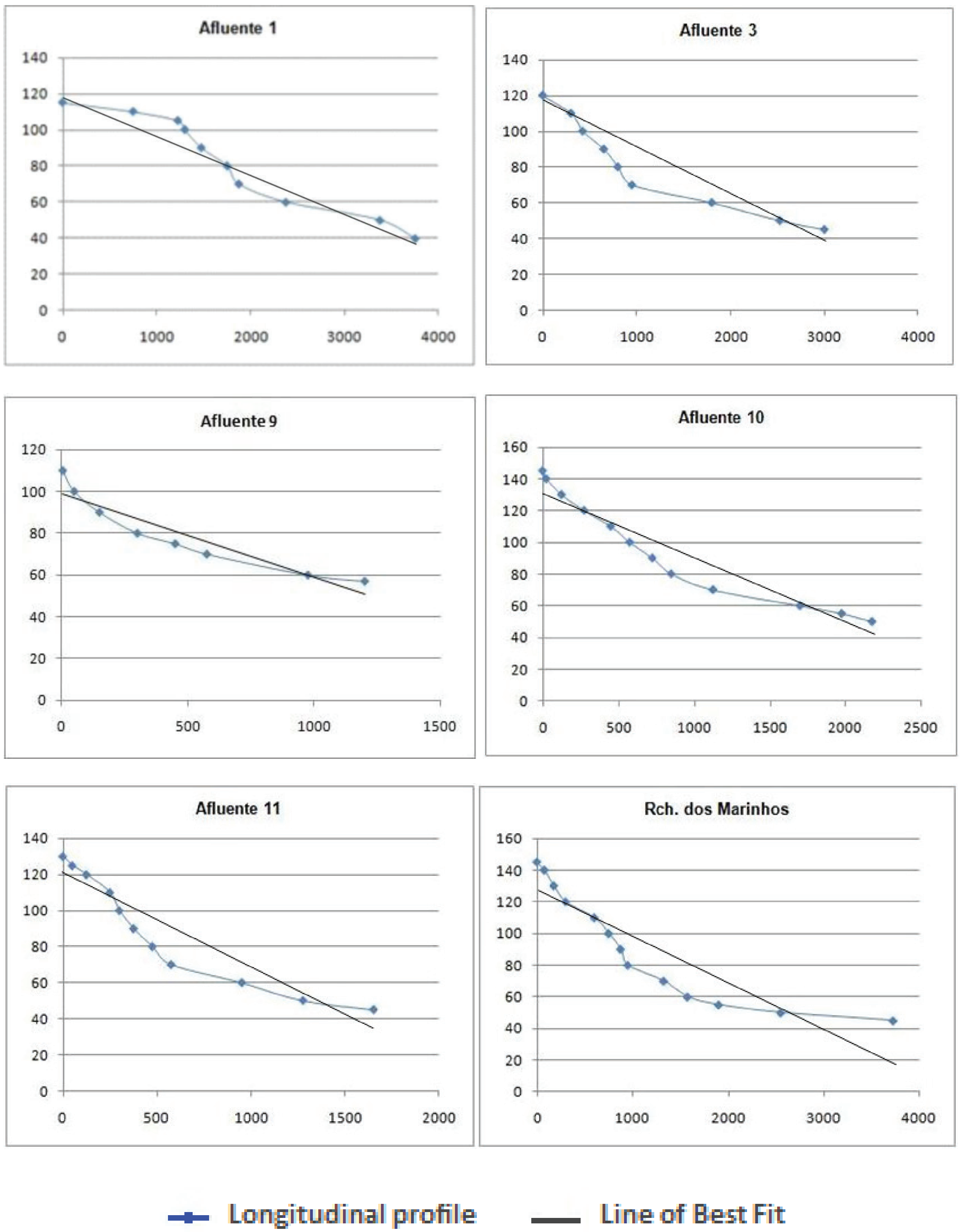

Figure 3. Longitudinal profiles of the courses that had a well above average RDE value.

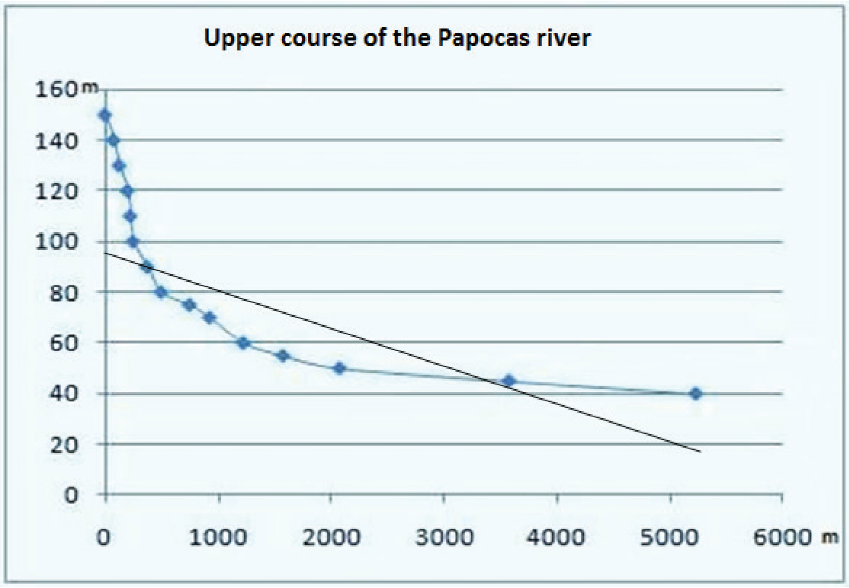

Figure 4 . Longitudinal profile of the upper course of the Papocas river, plus the Line of Best Fit.

Denomination of river	Straight (m)	Course of the river (m)	Altitude difference (m)			SGI (Slop vs Length)
1	3150.2	3823.4	115	40	75	91.04
2	771.9	836.6	105	45	60	65.02
3	2458.3	2958.2	120	45	75	90.25
4	1092.4	1212.2	110	45	65	72.12
5	1297.5	1452.7	120	55	65	72.78
6	283.3	289	80	60	20	20.41
7	541.3	596.3	100	70	30	33.04
8 (Papocas river)	7027.9	7774.2	130	35	95	105.08
9	1028	1118.2	100	55	45	48.94
10	1232.8	1651.2	140	55	85	113.84
11	1423.9	1537.4	135	45	90	97.17
12	421.2	483	60	45	15	17.20
13 (Str. of Marinhos)	3276.5	3689.5	145	40	105	118.23
14	559.7	640.9	100	55	45	51.52
15	931.2	952.2	100	40	60	61.35
16	1725.8	1735.7	70	35	35	35.20
17	650.2	674.3	90	40	50	51.85
18	380.9	408.6	80	40	40	42.91
19	886.7	893.3	50	30	20	20.14
20	909.5	1062.7	95	30	65	75.94
						Average: 64.21

Table 1. Calculation results of a section of the river Papocas' RDE.

The RDE index results indicate that the energy of some water courses is influenced by the uplift of the land, which contributed to the rise of the RDE values, e.g. the course number 10. That course has an RDE index of 113.84, with a watercourse of 1651.2 m; while number 16 has an RDE index of 35.2 (well below average, which is 64.21), with a watercourse of 1735.7 m, suggesting a influence of strong slope of course to the first, possibly due to an episode of uplifting of the board that limits them. Affluent number 9 also has a below average RDE index, and its longitudinal profile is the closest to the Line of Best Fit.

Although the area under consideration is relatively small, we can divide it into three parts, where it's possible to realize that the higher values of RDE are located in the headwaters of the tributaries, a part that is characterized by high power drainage excavation and bordered by more abrupt slopes of a long tableland. Not coincidentally, this is the area where the anomalies in the values of RDE are concentrated, and is also the part of the study area that concentrates the most intense processes eroded.

In the other two parts there is no indication in field, or much less in the analysis of the morphometry of the channels, that there is some sort of interference in the tectonic setting of the drainage. It is important to note that, in general, there is not a universal absolute value to serve as a comparison to the values obtained in this analysis. The RDE values are relative, and depend heavily on the substrate through which passes the drainage network.

5. CONCLUSIONS

The results obtained from the study of longitudinal profiles, followed by applications of the morphometric analysis were adequate to confirm the hypotheses about the presence of a modern tectonic in the study area.

It's possible to conclude, with the observation of the previous graph (Figure 3) and some of the longitudinal profiles in Figure 3, that the anomalies of the courses that present high values of RDE usually occur before the 2000 m toward the source of each tributary, suggesting that the entire area around the upper course of the Papocas river's basin is undergoing a process of dynamic adjustment resulting from neotectonic movement reflected in the geomorphology of the area.

There has to be considered a second hypothesis to attempt to explain these influences on the drainage courses of the part of the river analyzed: the chance that the area is no longer suffering tectonic interference, but there still are consequences of past tectonic that were not eliminated by superficial dynamic processes.

There are no low RDE values of the upper course of the Papocas, but to a lesser extent by the course of the tributaries examined. The results obtained through calculations, plus information obtained in the field, to strengthen corroborate the theory of interference neotectonics character modeled on the ascension of relief and, consequently, on course of the rivers in the area.

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