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Detail geomorphological mapping proposal: a practical application in tabular relief

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ABSTRACT

The present research aims to apply a methodology of geomorphological mapping of detail in tabular relief to help the understanding of the current geomorphological framework of the high and medium course of the Mamuaba River, located in the coverage area of the Mamuaba River topographic chart, in the State of Paraíba, Brazil. The research has a strong geological and structural focus with analysis of the interrelationships existing between lithology, morphology, morphometry and hydrography of the area. On the surface, the Barreiras Formation represents most of that area, covering, in a discordant way, a portion of the Paraíba Sedimentary Basin to the east, and the crystalline basement to the west. For the classification of the relief and elaboration of the geomorphological mapping, it was used, with adaptations to the peculiarities of the local relief, the methodology of Ross (1992), which is based, mainly, in the morphological and morphometric aspects. The technical and operational procedures consisted of the vectorization of the Mamuaba River topographic chart, on the scale 1: 25,000, which has contour lines with an equidistance of 10 m. Among the general aspects of the region's morphology, the presence of successions of grabens, horsts and topographical domes stands out in a structural character; and, as of sculptural character, current forms such as gullies, sliding scars, ravines and areas in the process of sanding.

Keywords: Paraíba Sedimentary Basin; Barreiras Formation; Embratel Dome.

Proposta de mapeamento geomorfológico de detalhe: uma aplicação prática em relevo tabular

RESUMO

A presente pesquisa tem por objetivo aplicar uma metodologia de mapeamento geomorfológico de detalhe em relevo tabular para auxiliar o entendimento do quadro geomorfológico atual do alto e médio curso do rio Mamuaba, localizado na área de abrangência da carta topográfica Rio Mamuaba, no estado da Paraíba. A pesquisa possui forte enfoque geológico e estrutural com análise das inter-relações existentes entre a litologia, a morfologia, a morfometria e a hidrografia da área. Em superfície, a Formação Barreiras representa a maior parte da referida área, recobrando, de forma discordante, uma parcela da Bacia Sedimentar Paraíba a leste, e do embasamento cristalino a oeste. Para a classificação do relevo e elaboração do mapeamento geomorfológico, utilizou-se, com adaptações às peculiaridades do relevo local, a metodologia de Ross (1992), que se apoia, principalmente, nos aspectos morfológicos e morfométricos. Os procedimentos técnicos e operacionais consistiram na vetorização da carta topográfica Rio Mamuaba, na escala 1:25.000, que possui curvas de nível com equidistância de 10 m. Dentre os aspectos gerais da morfologia da região, destacam-se de caráter estrutural a presença de sucessões de grábens, *horsts* e de domos topográficos; e, como de caráter escultural formas atuais como voçorocas, cicatrizes de deslizamento, ravinas e áreas em processo de arenização.

Palavras-chave: Bacia Sedimentar Paraíba; Formação Barreiras; Domo da Embratel.

Introduction

The research area covers the Mamuaba River topographic chart, where part of the municipalities of Alhandra, Pedras de Fogo and Santa Rita are inserted. This one was selected for this work because it has relevant geological,

geomorphological and environmental aspects, since this region is in a frank process of real estate speculation and expansion of the sugarcane culture. In this area are located the headwaters of two watersheds of great importance for supplying the Metro João Pessoa, which are the watersheds of the

Gramame and Mamuaba rivers. Several cities, communities and farmers in the region also collect water from these watersheds.

The main focus of this research is to propose a detailed characterization of geomorphology by elaborating a detailed geomorphological map that serves as a subsidy to the general understanding of the main forms of relief in its various categories of analysis.

The forms that make up today's landscapes reflect the processes of millions of years of work by agents who slowly molded the earth's surface. Therefore, it can be emphasized, also, that each form of relief has its own history, being important to learn to interpret and map them, because in the geological past there was no one to observe the events and document what happened. observed (Ross, 1992).

It is in this context that relief studies become essential, as it is on this component of nature that all human and economic activities are developed. Therefore, its morphology directly influences the forms of occupation and uses. Given this approach, it is possible to establish guidelines for analyzing the different processes that gave rise to the relief model and the factors that contributed to its evolution over time, taking into account hydrographic patterns that may be directly influenced by lithological differentiation or by the performance of tectonic processes (Soares; Fiori, 1976; Andrades Filho, 2010; Kulkarni, 2015).

Detailed knowledge of the configuration of the relief is essential in the elaboration of mitigating measures regarding the use and occupation of the soil and the geomorphological map can be an important instrument in the elaboration of proposals for environmental and spatial planning (Furrier, 2018). The relationship between geomorphology versus soils in coastal boards sculpted over the Barreiras Formation needs more detailed studies. Many pedological characteristics are misinterpreted in many geological works (Freitas et al., 2012).

In this research, there is a focus on geomorphological studies based on the assumptions established by the General Geomorphology guidelines, considering the direct influence of the geological and tectonic structure in the current configuration of the relief, which can be represented, in the case of the present research, by geomorphological cartography. Santos et al. (2016) indicate that the geomorphological analysis, when considering the influences of the geological substrate in the formation and configuration of the

relief, can be represented cartographically by morphostructural units.

In order to elaborate a geomorphological mapping, it is necessary to seek a methodology that best approximates the elements that the researcher is trying to represent (Antunes and Ross, 2018) and, during the mapping, make the necessary methodological adjustments for the correct adaptation to the mapped relief. Therefore, the geomorphological cartographic material produced in this work considered the methodology proposed by Ross (1992) with adaptations by Furrier and Gonzalez (2015) and Souza and Furrier (2019) for adaptation to the local relief, predominantly tabular. This geomorphological mapping methodology is based mainly on morphostructural and morphosculptural aspects.

In this perspective, several studies have been developed on the eastern edge of Northeast Brazil and showing satisfactory results, such as the works of Rodrigues and Oliveira (2007), Barbosa et al (2015), Barbosa, Furrier and Souza (2018), Souza and Furrier (2019), Silva and Furrier (2019), Furrier and Silva (2020). These works developed geomorphological mappings associated with the structural characteristics of the terrain resulting in a detailed assessment of the area, since the generated products made possible the representation of the geomorphological elements and expanded the understanding of the peculiarities of the relief.

The choice of the topographic chart as a database for this research is justified by the excellent quantity and quality of details that it provides, since it is a chart in the scale 1:25,000 with equidistance of the 10m contour lines. To test the reliability of the information provided in the topographic chart, georeferenced points were plotted in the field with global positioning system (GPS) and also in Google Earth Pro.

This topographic chart was prepared by the *Superintendência de Desenvolvimento do Nordeste* (SUDENE) in 1974, using triangular aerophotogrammetry and technical support on the ground, which gives it high precision, much higher than the Shuttle Radar Topography Mission (SRTM) images with resolution of 30m, according to tests proven by Santos et al. (2015), Souza and Furrier (2019) and Furrier e Silva (2020) for detailed scales.

Due to the deficit of planialtimetric mapping in Brazil at large and medium scales, there is a difficulty in obtaining and processing topographic information at these scales. However, the use of new technologies and the availability of

free Geographic Information Systems (GIS) has become increasingly common, allowing the elaboration of these cartographic products (Souza, 2015).

In this way, this research seeks to produce detailed relief information bringing unprecedented results to the study area with reliable data from the elaboration of thematic maps and scaled models of the geomorphological units that allow the understanding of the relationships between the relief and the lithological pattern and the hydrography of the area.

Geological-geomorphological aspects of the area

The investigated area is located in the mesoregion of Zona da Mata in the State of Paraíba, Northeast Brazil, and has a total area of 196 km². Within the limits of the chart, there is a large part of the watershed of the Mamuaba River and the upper course of the Gramame River (Figure 1). These watersheds are composed of several tributaries, the most expressive being the Vermelho River, Buraco River, Fundo River, Jangada River, Grilo River and Santa Cruz Creek.

Figure 1. Geographic location of the study area.

The study area is, for the most part, on poorly consolidated sandy-clayey sediments from the Barreiras Formation (Miocene). In the eastern sector, the Barreiras Formation covers the Paraíba Sedimentary Basin. In the western sector, the Barreiras Formation covers the crystalline terrain of the Alto Moxotó (Neoproterozoic). This terrain is diagonally towards the central-eastern portion of the Transverse Zone of the Province of Borborema, resulting in a general trend from NE to E-NE (CPRM, 2002; Brito Neves et al. 2016; Brito Neves; Schmus; Santos, 2020) (Figure 2).

The Paraíba Sedimentary Basin is filled with sediments of continental and marine facies, gathered under the name of Paraíba Group, which, in turn, is subdivided into three formations: Beberibe, Gramame and Maria Farinha (CPRM, 2002; Barbosa et al. 2004), the first being clastic and the other two carbonates. This Basin has its genesis and evolution directly related to tectonic events, which gave rise to the South Atlantic Ocean, during the separation of the African and South American continents (Asmus, 1975; Françolin; Szatmari, 1987; Bezerra et al. 2014).

In the extreme west, there is a small granite outcrop of the Alto Moxotó terrain, belonging to the crystalline complex of the Borborema Province (CPRM, 2002; Guimarães et al. 2017; Brito Neves; Schmus; Santos, 2020). This outcrop is located between the sources of the Gramame and Mamuaba rivers, being the topographic divider between these two sources. In the portion that corresponds to the low course of the Mamuaba River, according to Brito Neves et al. (2009), it is possible to verify the outcrop of the Beberibe Formation along the entire length of the river channel. This sedimentary formation differs from the Barreiras Formation due to its mineralogical composition (Rossetti, 2012).

From the adjustment made to the geological map through fieldwork, it was possible to identify four geological units in the area, which are: indiscriminate Neoproterozoic granitoids, Beberibe Formation (Cretaceous), Barreiras Formation (Miocene) and alluviums (Quaternary). Although the geographical scope of the Barreiras Formation is predominant, the other three formations cannot be neglected, due to its importance in the configuration of the relief and the hydrographic network.

At the bottom of the river valleys there is the outcrop of the Beberibe Formation, due to the process of intense river incision and deposits of alluvial sediments forming plains and terraces embedded. For a better geological characterization of the area, the geographic distribution of the geological formations was summarized as follows (Table 1).

About the Barreiras Formation, the Low Coastal Plateaus (Coastal Tablelands) are developed, which are generally tabular surfaces that advance to the coastline when they form cliffs. The Coastal Tablelands occur in practically all the coast of the Northeast of Brazil. They have as characteristics a flat topography with a smooth undulation and low altitude, with an average slope of less than 10% (Embrapa, 1994). These general

morphological characteristics of the Coastal Tablelands are conducive to mechanized and large-scale cultivation of sugar cane.

The soils are deep and have low natural fertility due to intense leaching. These boards, now raised, lowered and tilted, gave rise to the system of grabens and horsts of the Mamuaba river under direction NNE-SSW, proceeding to the confluence Mamuaba-Gramame (Brito Neves et al., 2009).

In the studied area, the Low Coastal Plateaus are reliefs composed of gentle elevations, which have semi-tabular flat tops, forming small plateaus with a gentle dip towards the coast (Figure 3a). The altitudes are generally less than 100 m in the eastern direction, and increase slightly in the western direction, reaching, in some points, altitudes above 200 m.

Still on local geomorphology, in addition to the Low Coastal Plateaus, the dome structures predominate in the region, yet without a fully clarified genesis. One of the most striking and characteristic structures of the local relief is the Embratel Dome, which is more or less in the center of the Mamuaba River topographic chart, and is an extremely important topographic divider separating the drainage networks in the upper course of the Mamuaba and Gramame rivers.

In the area of crystalline exposure, the relief is gently wavy, forming a depression with low hills. The valleys in these areas are shallow, crossed by predominantly temporary rivers (Figure 3b).

The active climate in the study area is humid tropical and the average annual temperatures are around 25 °C, with rainfall levels ranging from 1,500 to 1,700 mm, with rains well distributed throughout the year, being more intense in the autumn and winter months and without presenting totally dry months (Alves et al., 2009). These climatic characteristics added to the tabular top relief give the area a strong chemical weathering and a high leaching rate, which generates naturally poor soils with a high concentration of quartz.

Figure 2. Geological map of the study area. Adapted from Sudene (1974), CPRM (2002) and Brito Neves et al. (2009).

Table 1 - Measurements of geology classes in km² and percentage.

Classes	Area (km ²)	Area (%)
Alluvial	10.22	5%
Barreiras Formation	173.19	90%
Beberibe Formation	5.36	3%
Granitoids	3.63	2%

Methodological procedures

To support the proposed research, firstly cartographic and bibliographic materials were gathered that helped the geomorphological mapping and gave theoretical consistency to the research. To obtain, analyze and quantify the physical characteristics of the terrain, the Mamuaba River topographic chart in the scale of 1: 25,000 was used as the base instrument, showing equidistance between the 10 m contour lines, which provides excellent precision.

In geomorphological mapping, the notion and care that should be directed towards the concept of scale is essential. Authors such as Ross (1992) and Costa et al. (2020) highlight the importance of scale in the treatment and representation of relief in the degree of detail or generalization of information, as it is the scale that will determine the adoption of different strategies and approach techniques.

Large-scale charts allow mapping more specific local landforms, showing the current and anthropic processes in the elaboration of the model (ravines, gullies), while smaller-scale maps allow mapping large extensions, such as Morphostructural Units, Geomorphological Regions (Brazil, 2009) and Morphosculptural Units (Ross, 1992).

The choice of a scale of 1: 25,000 is justified by the excellent quantity and quality of details, allowing the identification of the six taxons proposed in Ross's methodology (1992): Morphostructures (1st taxon), Morphosculpture (2nd taxon), denudational and pleasant morphological units (3rd and 4th taxon), slopes (5th taxon) and the smallest forms of relief - current and anthropic processes (6th taxon).

Figure 3. (a) Characteristic relief of the Low Coastal Plateaus in the middle course of the Mamuaba River. (b) Characteristic relief of the granite exposure area in the upper course of the Gramame River.

The procedures started with obtaining the Mamuaba River topographic chart provided by SUDENE and, soon after, its digitization, being vectorized in the QGIS 3.12 software. The vectoring procedure was manual, which provided the necessary precision and a thorough analysis of the area, since each level curve was vectored, which provided very reliable results. The following elements were vectorized: contour line, hydrography, spot elevation, road network and administrative limits. According to Barbosa and Furrier (2012), with manual vectoring, the operator has full control over the tracing established with the mouse, thus making it possible to obtain more accurate data.

The geomorphological map was produced based on the methodology proposed by Ross (1992), with some adaptations made by Furrier and Gonzalez (2015) and Souza and Furrier (2019) to adapt to the predominantly tabular scale and relief of the area. The procedures adopted in making the mapping were polygonal vectoring, followed by cartographic conventions adapted from the IBGE (Brasil, 2009).

Ross (1992), based on Penck's methodological conceptions in 1953, took the forms and scope of each taxonomic unit as classification parameters. In this way, the author established six taxonomic levels, namely: morphostructure, morphosculpture, patterns of relief forms, types of relief forms, types of slopes and forms of current natural and man-made processes.

For the elaboration of the topographic profiles, the software QGIS 3.12 was used on the shaded image with the level curves and the elevation dimensions. For this purpose, three stretches were selected in the latitudinal direction and one section in the longitudinal direction for demonstration. After the profiles were drawn, the generated images were edited, defining their vertical exaggeration and other necessary toponymy.

For the altimetric map, intervals were considered every 20 m, up to the limit of 220 m, which is the highest point in the area. Each height elevation generated received a specific color. This coloring must follow parameters that best represent the differentiation of the relief. The colors corresponding to each elevation dimension were established considering the guidelines of Furrier (2018) and Furrier and Silva (2020), who developed works using altimetric charts in the preparation of environmental fragility charts and in tectonic studies.

The slope map was elaborated from data constructed for this study, being, therefore, compatible with the scale of the work. According to Barbosa and Furrier (2015), the declivity classes can be represented in degrees or in percentages. For this study, we opted for representation in percentages, following the methodology proposed by (Embrapa, 2006).

In order to adjust the geological map presented in this research, were consulted and used the geological mapping developed by the Geological Service of Brazil (CPRM, 2002) on the scale of 1: 500,000 and the geological survey carried out by Brito Neves et al. (2009) on a scale of 1: 50,000. Therefore, some adaptations were necessary for the map to be adjusted to the scale of 1: 25,000. The Digital Elevation Model (DEM), as well as the satellite images, made it possible to update some information on that map and increase the level of detail regarding the lithology of the study area.

A step of fundamental importance within this research were the fieldworks. As it is a relatively great area, the fieldwork was carried out after the creation of the thematic maps generated (altimetry, slope and DEM) and with the help of satellite images, the main points of field study were traced, referring to the steepest slopes, occupied floodplains and anomalous river channels. Field observations were essential for adjusting the geological map and making the geomorphological map.

Results and discussions

Altimetry, slope and hydrography

Even though it is inserted in a passive continental margin, the eastern border of the state of Paraíba shows a strong influence of post-Myocene tectonic movements very well visualized in the Barreiras Formation, resulting mainly from the reactivation of Precambrian ductile shear zones, due to the constant spacing from South America (Hasui, 1990; Brito Neves et al. 2004; Furrier et al. 2006; Andrades Filho, 2010; Bezerra et al. 2014). This structuring produced a very heterogeneous geomorphological compartmentalization over the Barreiras Formation, with altitudes in the study area of 20 to 213 m (Figure 4a).

The altimetric map developed was configured as an important tool, mainly for geomorphological analyzes. This technique allows, among others, the representation of the elevation of a relief and its relationship with the incision of the

river valleys, which are also quite heterogeneous in the region.

Two main characteristics can be observed in the Mamuaba River watershed: (1) the sharp elevation difference between the Low Coastal Plateaus located on the right and left of this watershed, whose altitudes reach the board located on the right, 213 m, and those located at to the left of the watershed the maximum altitudes are 130 m, totalling a difference of 83 m in altitude between the two boards that confine the Mamuaba River and are only 5 km apart. This sharp elevation difference between the Low Coastal Plateaus corroborates the idea of post-Myocene reactivations in the area, since the boards have the same lithology and age, as they were developed on the Barreiras Formation; and (2) in local geomorphology, it is possible to notice, in addition to tabular morphology, a dome structure, totally anomalous, when compared to the predominant tabular relief developed over the Barreiras Formation (Figure 4a).

The dome formation verified in the area, in addition to being the main dividing point of the two main drainage networks, produces a centrifugal radial drainage pattern, with the influence of this topographic landmark in most of the springs of the water courses being notorious.

Studies carried out by Alheiros and Lima Filho (1991) proclaimed for the Barreiras Formation a dip in the eastern direction towards the Atlantic Ocean, and this verified dome shape deconstructs this statement, as its elevation level is higher than that verified in the west, contrary to the sense of dive of the Barreiras Formation. Therefore, its shape and superior altimetry cannot be explained only by the climatic factor of development of the relief in considerable stable areas.

As a support for the broader and more detailed characterization of the relief, a slope map of the area was elaborated, which helped in the identification and correlation of the declivity with the geomorphic features and their possible relationship with the tectonics, given the great heterogeneity of the slope classes found.

Observing the slope map (Figure 4b), it is possible to check the limits of the Mamuaba River watershed, where higher declivity are observed on the right bank of the channel, with values ranging from 45% to 75% more frequently, in addition to showing with the high notches formed by the drainage networks are quite clear. Highlight especially for the strong carvings that the Fundo

and Buraco rivers present, whose slopes reach more than 75% of declivity near their sources.

In the sector where the Embratel Dome is located, it is possible to observe the biggest declivities in the area under analysis, with high carvings with slopes that reach up to > 75% slope, with rivers embedded in their respective valleys. The high declivities observed in the slopes around the dome formation attests to a sharp setback in the springs of the streams and the sharp dissection of the entire dome.

Due to the altimetric difference between the tablelands bordering the Mamuaba River channel, it is possible to observe an asymmetric drainage network. According to Andrades Filho (2010), the importance of analyzing such features and drainage anomalies occurs, mainly, when the lithological substrate is homogeneous, as is the case. When the asymmetry of the drainage network of a watershed occurs on the same lithological substrate, the anomalies are seen as strong evidence of tectonic control.

In the watersheds under study, anomalies in the drainage pattern are easily observed, such as, for example, the inflection in the medium and low course of the Vermelho River and the Santa Cruz Stream, and the straightness that the Buraco and Fundo rivers present in their medium courses. (Figure 5).

The straightness of water courses in sedimentary terrains, consisting of poorly consolidated rocks, is strong evidence that this course is adjusted to a fault line. The rivers of Grilo and Mundo Novo seem to fit in the cases of “valley of fault line”, that is, rivers that follow exactly the fault line, being straight and long.

Rossetti et al. (2012) cited the existence of fault zones in the Paraíba Basin that define important drainage lines, for example: the Gramame, Mumbaba, Mamuaba and Paraíba rivers. Thus, the strong inflections of the studied rivers may be linked to the faults, also presenting, in the vicinity of the sub-basins, very different topographic unevenness for a sedimentary cover and atypical drainage patterns, such as the lattice pattern in the tributaries of the Jangada River.

The lattice pattern usually develops in alternating valley valleys and ridges, with folded rocks composed of materials of different levels of resistance to erosion. Therefore, this small watershed may already be under the influence of the crystalline terrain adjacent (Figure 2 and 5).

Figure 4. (a) Altimetric map highlighting the 3D relief pattern, (b) slope map.

It is possible to observe, with great clarity, the nuances of the relief of the area with the strong indentations of the first order flow, mainly in the south sector, besides the accentuated asymmetry of the watershed with the tributaries of the right bank of the Mamuaba River much more advanced and carved than the tributaries of the left bank. This difference between tributaries on opposite sides of the main channel is understood by Soares and Fiori (1976) as an indication of tectonic activity in the configuration of watersheds.

Geomorphological map

The bibliographic review and systematic analysis of the data found in the topographic chart, associated with information contained in the altimetric and slope maps plus direct observations in the field, favoured the elaboration of the

geomorphological map. Based on the construction and analysis of this cartographic product, two morphostructures for the area were identified: Paraíba Sedimentary Basin and Alto Moxotó Terrain. Each of these morphostructures were subdivided into taxonomic units of lower hierarchical value (Figure 6).

The 2nd taxon is basically composed of three morphosculptural classes, sculpted on the two morphostructures that are: the Low Coastal Tablelands, the Dome Surfaces and the Eastern Borborema Depression. The 3rd and 4th taxon correspond, respectively, to the patterns and types of landforms (Figure 6).

Figure 5. Main asymmetries in the river channels.

Figure 6. Geomorphological map.

The verification of the geomorphological map of the area allowed to observe that the first taxon present in the area includes the geological units of the quaternary sediments, therefore, in the area in question, these sediments are represented by the Barreiras Formation and the alluviums. These alluviums can be observed in relief forms of fluvial terraces and plains fluvial (**Atpf**) present, for the most part, in the valley of the Mamuaba and Gramame rivers and at the confluence of these rivers with their main tributaries.

It should be noted that the name **Atpf** (**Accumulation: terrace and plain fluvial**) is being used in this research due to the scale adopted and the peculiarities of the area's relief, which do not allow the distinction between terraces and plains through mapping. This unit is originated from accumulation processes, therefore, it has no numerical value of representation in the 4th taxon, since these values refer to the dissection levels.

Five denudational forms were mapped in the area. For a better understanding, they will be analyzed and detailed separately.

Dt 31 (Dissection: tabular): are forms of tabular dissection with notched valley of medium intensity and with an interfluvial dimension classified as very large. This type of shape is located in the northern sector of the area, on the left bank of the Mamuaba River. This relief is characterized by forms with tabular tops. This top model is an indication that the dissection process has not yet taken place in a very significant way in this area, preserving the tabular top characteristic (Figure 7).

Dt 41 (Dissection: tabular): dissection type with tabular shapes, with strong carving of the valleys (80 to 160 m) and very large interfluvial dimension (> 1,500 m). This type of shape can be found in the central portion of the area, between the right bank of the Mamuaba River and the left of the Gramame River. This form of relief is sculpted on the Low Coastal Tablelands. Unlike Dt 31, this tabular form is already a little more dissected by the erosive work of the water courses that cut it.

Figure 7. Relief with tabular top and low degree of dissection.

In this relief sector, the formation of triangular facets can be observed, which are indicative of areas that have undergone recent uplift and had their edges exposed to erosive processes. The triangular facets observed on the left bank of the Gramame River, in Dt 41 (Figure

8), suggest that this region was submitted to a recent tectonic uplift, characterizing, thus, neotectonic activity in this area. It is worth mentioning that these facets are sculpted on the same lithology (Barreiras Formation).

Figure 8. Formation of triangular facets in sector Dt 41.

Dt 42 (Dissection: tabular): represents a denudational unit of forms with a tabular top, notching of index 4 valleys (80 to 160 m), classified as strong, and large interfluvial dimension (1500 to 700 m), located in the southern portion of the chart, in right bank of the hydrographic basin of the Gramame River, passing through the Ibuíra and Pitauga streams.

Dd 41 (Dissection: dome-shaped): Dd 41: On the left bank of the Mamuaba River, close to its source, there is the denudational relief form named in this research by Dd. This form of relief with a degree of dissection 41 can be interpreted as a dome surface still partially dissected by hydrography. It presents a carving of the valleys, with a depth considered to be strong, ranging between 80 and 160 m, and a very large interfluvial dimension, greater than 1,500 m. In this value of dissection, the dome formation becomes more evolved and visible in the landscape.

Dd 51 (Dissection: dome-shaped): This relief pattern has a dome circular shape, with a very strong middle notch in the valleys (> 160 m) and a very large average interfluvial dimension (> 1,500 m). These dissection values suggest that this strong incision was due to aggressive erosive processes, and also demonstrate that the dome structure is in a clear denudational process, due to its high altimetry and the high declivities presented in the slopes, which, in turn, increase the energy and erosion power of water flows.

The pattern and type of relief resulting from this process correspond to the representative structure of a circle with radial drainage. This area is known as the Embratel Dome because it has a telephone tower at the top. This relief is in the process of strong dissection by the tributaries of the Mamuaba River, to the north, and Gramame, to the south (Figure 9).

Figure 9 - Relief with a dome circular surface.

For the interpretation and analysis of the 5th taxon, topographic profiles of S - N and W - E were drawn. With the completion of these profiles, it was possible to visualize several forms referring to the configuration of the slopes. The profiles were made in lines that follow the outline of some coordinates of the Mamuaba River topographic chart. In total, four profiles were applied that represent all taxon and their different dissection values (Figure 10).

The A-A' (S-N) profile includes the relief compartments Dt 42, Dt 41, Dd 51 and Dt 31, crossing the Gramame and Mamuaba rivers. In this profile, there was a predominance of rectilinear slopes. This profile clearly showed the graben structure presented by the Mamuaba River valley, which is confined between two horsts. In addition, the imposing circular dome shape present in the area of Dd 51 can be clearly seen (Figure 11).

The B-B' profile (W-E) was drawn on the relief of the compartments Dd 41 and Dt 31. This profile shows a predominantly flat relief forming extensive trays little dissected by the drainage. In the area of predominance of Dd 41, it is possible to note its characteristic dome shape. Comparing the profiles A-A' and B-B', the importance of these circular shapes in the configuration of the relief of the area is verified. This profile is drawn over the highest altitudes.

In the C-C' (W-E) profile, the compartments Dt 31 and Dt 41 are present, and it is possible to observe in this route the strong indentations caused by the Fundo and Buraco rivers. The slopes found are quite varied, being possible to verify, for example, the rectilinear slopes in the rivers Mundo Novo and Jangada and concave in the Fundo River. The Buraco River has two types of slopes: on the left bank it has slopes with a concave shape, and on the right bank it has rectilinear slope. Observing the Vermelho River, it

was found that it also has two types of slopes: on the left side a convex slope, and on the right side a rectilinear slope.

The D-D' (W-E) profile demonstrates the strong dissection carried out mainly by first-order streams in the southern region of the area. Larger carvings are verified in the valleys of the streams of Bezerro, Angelim and Botamonte, with predominance of straight lines in this profile. In the aforementioned streams, asymmetrical valleys can be observed showing signs of tipping in the W-E direction. Between the slopes of the Angelim and Botamonte streams, the formation of triangular facets can be seen, reinforcing the evidence of tectonic activity in the area.

The 6th taxon corresponds to small forms of relief, such as those resulting from current processes, for example: ravines, gullies, silting banks, in addition to forms produced by man, such as cuts and embankments, among others.

For the area under study, current forms referring to heterogeneous formation processes, such as: gullies (Figure 12a), sliding scars, ravines and areas in frank sanding process, were identified through field work and analysis of satellite images.

Regarding the anomalous features found in the area, it can be observed in the geomorphological map: (a) structural domes; (b) shape related to the tectonics that gave rise to the graben and horsts system of the Mamuaba River; (c) crystalline outcrop; (d) presence of drainage headwaters in an amphitheatre, mainly at the sources of the Mamuaba, Mundo Novo and Grilo rivers; (e) triangular facets in homogeneous lithology, which is a strong indication of recent tectonic disturbances; and, finally, (f) numerous drainage anomalies present in several channels in the area.

Figure 10. Location of the topographic profiles.

Figure 11. Topographic profiles with respective lithologies.

Figure 12b).

Figure 12. (a) Gully near the tributary of the Jangada River. (b) An area in the process of sanding near the Embratel Dome. Image: Bing Maps (2016).

Final considerations

Detail geomorphological mapping is of great importance, since the relief has an influence on various physical and social aspects, such as: in the distribution of vegetation, in the configuration of drainage and in human activities. The detailed knowledge of the relief provides subsidies for planning and spatial ordering, and can serve as a

basis for preparing studies with the same perspective in other areas.

The geomorphological map presented allowed to identify two morphostructural units, three morphosculptural units and eight patterns of different relief forms. In addition, it was still possible to identify the forms and types of slopes, highlighting the convex, rectilinear and convex-rectilinear slopes. For the 6th taxon, current forms

were identified referring to heterogeneous formation processes, such as: gullies, sliding scars, ravines and areas in clear sanding process.

The results of the analyzes carried out in this research show a clear division of the relief in two distinct compartments visibly separated by a dome structure, and strong river notches with high slopes that, in some points, exhume underlying formations of the sedimentary basin. This dome structure is totally anomalous when compared to the predominant tabular relief developed over the Barreiras Formation.

The information presented on the features of the relief and its dynamics, as well as detailed quantitative and qualitative data, such as relief dissection, carving of valleys and gullies, make this research relevant and contribute to the occupations occurring considering the fragilities and potentialities of the environment, which favours, therefore, the sustainability and quality of life of society.

The use of this methodology proved to be quite satisfactory because it was possible to map small relief features almost never mapped in general geomorphological mapping more commonly existing. It is believed in the enormous potential of this methodology for new detailed geomorphological mappings in other areas of Brazil and abroad.

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