ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 6, nº 2 (2020)

https://doi.org/10.21680/2447-3359.2020v6n2ID18685

GEOMORPHOLOGY OF THE TERMINAL PORTION OF THE LOWER COURSE OF THE PARAÍBA DO NORTE-PB RIVER

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Abstract

This work aims to understand the geomorphological framework of the terminal portion of the lower course of Paraíba do Norte river- PB, through the classification and cartographic differentiation of the relief units present in the study area. For the present work, a scale of 1: 25,000 was adopted, which allowed identifying the six taxons proposed in Ross's methodology (1992). The study made it possible to know in greater detail the geometry and relief patterns in the region, where stood out accumulation and denudation areas, among them: fluvial, marine and fluvial-marine plains, terrace shapes and slopes, cliffs, beaches, sandy bars, sandbanks, beach paleolines, reefs, anthropogenic lagoons, lagoons, sink holes, and *sedimentation glacis*, besides tabular and convex relief forms that shape the coastal boards of the Paraíba coast.

Keywords: Geomorphology; Paraíba Coast; Paraíba do Norte-PB riverestuary.

GEOMORFOLOGIA DA PORÇÃO TERMINAL DO BAIXO CURSO DO RIO PARAÍBA DO NORTE-PB

Resumo

Este trabalho objetiva compreender o quadro geomorfológico da porção terminal do baixo curso do rio Paraíba do Norte – PB, mediante a classificação e diferenciação cartográfica das unidades de relevos presentes na área de estudo. Adotou-se para o presente trabalho a escala de 1:25.000 que permitiu identificar os seis táxons propostos na metodologia de Ross (1992). O estudo possibilitou conhecer com maior nível de detalhe a geometria e os padrões de relevo existentes na região, onde se destacaram áreas de acumulação e denudação, dentre elas: planícies marinhas, fluviais e flúvio marinhas, formas de terraços e vertentes, falésias, praias, barras arenosas, bancos de areia, paleolinhas de praias, recifes, lagoas antropogênicas, lagunas, dolinas e *glacis de* sedimentação, além de formas de relevos tabulares e convexos que modelam os tabuleiros litorâneos da costa paraibana.

Palavras-chave: Geomorfologia; Litoral paraibano; Estuário do rio Paraíba do Norte-PB.

GEOMORFOLOGÍA DE LA PORCIÓN TERMINAL DEL CURSO INFERIOR DEL RÍO PARAÍBA DO NORTE-PB

Resumen

Este trabajo objetiva comprender la imagen geomorfológica de la porción terminal del curso inferior del río Paraíba do Norte – PB, mediante la clasificación y diferenciación cartográfica de las unidades de relieve presentes en el área de estudio.Se adoptó una escala de 1:25,000 para el presente trabajo, lo que permitió la identificación de los seis taxones propuestos en la metodología de Ross (1992). El estudio permitió conocer con mayor detalle la geometría y los patrones de relieve existentes en la región, donde se destacaron las áreas de acumulación y denudación, entre ellas:llanuras marinas, fluviales y fluviomarinas, formas de terrazas y vertientes, acantilados, playas, barras arenosas, bancos de arena, paleolinas, arrecifes, estanques antropogénicos, lagunas, dolinas y *glacis* de sedimentación, además de formas de relieves tabulares y convexos que modelan los TablerosLitráneos de la costa de Paraíba.

Palabras-clave: Geomorfología; Costa de Paraíba; Estuario del río Paraíba do Norte-PB.

1. INTRODUCTION

The detailed geomorphology of an area makes it possible to know, in greater detail, the relief and geometry of the region's drainage patterns, revealing the natural potential existing in the area, facilitating the identification of risk areas, fragile environments, environmental impacts, anthropic interference and dynamics of evolution of natural landscape This work aims to understand the geomorphological framework of the terminal portion of the lower course of the Paraíba do Norte– PBriver, classifying and mapping the relief units. This terminal portion means the area corresponding to the lands of the Coastal Tablelands and Marine Plains where depositional, fluvial, estuarine, beach and shallow marine systems are found.

According to Maia and Bezerra (2012), the study of relief through cartographic bases and specific methodologies extracted from Geomorphology, Geology, Mathematics and Geoprocessing, becomes an effective means of investigating and analyzing the morphological pattern resulting from the interface between endogenous and exogenous agents.

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 structure and tectonics on the current configuration of the relief, which can be represented by geomorphological cartography. In this context, thematic mappings become essential in Geomorphology, mainly for physical-environmental planning, since the spatialization and location of the facts allow to represent and understand the forms of the relief and the dynamics of the active processes (ROSS, 1992; MARQUES, 2007; RODRIGUES; OLIVEIRA, 2007).

In geomorphological mapping, the notion and care that should be directed towards the concept of scale is essential. Authors such as Ross (2014) and Christofoletti (1980) highlight the importance of scale in the treatment and representation of relief in degree of detail or generalization of information, because the scale will determine the adoption of different strategies and approach techniques. For example, large scale maps allow mapping local punctual landforms, highlighting the current and anthropic processes in the elaboration of the model, while smaller scale maps allow mapping large sandy areas (BRAZIL, 2009; ROSS, 1992).

Thus, according to this understanding, the scale of detail of 1:25,000 was adopted for the present work, whose final products were published in the scale of 1:80,000. The choice of the 1: 25,000 scale is justified by the excellent quantity and quality of details, allowing to identify the six taxa proposed in the Ross (1992) methodology.

For Souza (2015), "due to the deficit of planialtimetric mappings, in large and medium scales, in Brazil [...], there is a difficulty in obtaining and processing topographic information in 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. As an example, the works elaborated by Rodrigues and Oliveira (2007), Barbosa, Furrier and Souza (2018) can be cited, which have been developing geomorphological mappings associated with the structural characteristics of the land resulting in a detailed assessment of the area, since the products generated enable the representation of geomorphological elements and expand the understanding of the peculiarities of the relief.

In this same perspective, the present research offers detailed relief information bringing unprecedented results to the study area with reliable data, given that the topographic maps used as a base were produced by planialtimetric aerial survey with ground support, with a high detail. In this way, it was possible to elaborate thematic maps and specific scalar models of the geomorphological units that allowed the understanding of the relationships between the relief and the lithological pattern, highlighting the features resulting from the interface between both, which, associated, originate the physical configuration of the area.

2. CHARACTERIZATION OF THE STUDY AREA

The studied area is delimited by a polygonal that covers the terminal portion of the lower course of the Paraíba do Norte – PB river, between the UTM plane coordinates 9,231,000 mN to 9,211,000 mN and 291,000 mE to 301,000 mE, Datum SIRGAS 2000, zone 25S (Figure 1), covering the municipality of Cabedelo and part of the municipalities of Lucena, Santa Rita, Bayeux and João Pessoa.

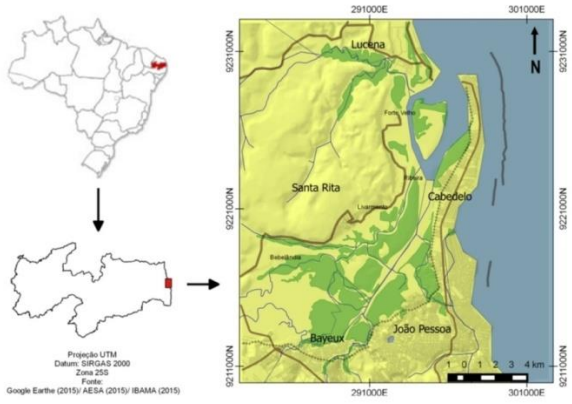


Figure 1 – Location of the study area. Source: Lavor (2016). Note: delimitation of the Paraíba do Norte river estuary in green; the yellow color represents the lands of the Coastal Tablelands and Marine Plains of the area.

The area is inserted in the central-eastern portion of the Paraíba Basin, which is filled with sediments of continental and marine facies, gathered under the name of Paraíba Group, which, in turn, is subdivided into five Formations: Beberibe, Itamaracá, Gramame, Maria Farinha and Tambaba (BRAZIL, 2002; CORREA FILHO et al., 2015), consisting of medium, thick and conglomeratic sandstones of continental origin, and the rest of carbonate deposits. Covering the Paraíba Group, but not being part of it, is the Barreiras Formation, of continental origin. This Formation consists of the most continuous lithostratigraphic unit along the Brazilian coast, occurring from the State of Pará to Rio

de Janeiro. It is characterized by the presence of facies of an interlaced and transitional fluvial system for fluvial fans, of varying granulometric deposits, presenting gravels, coarse and fine sands of yellowish color, with intercalations of silts and clays (ALHEIROS et al., 1988).

About the Barreiras Formation and/or constituting the most superficial levels of the entire studied area, pleistocenic and holocenic sediments are located, which constitute the eluvial, colluvial and alluvial deposits (Figure 2 and Table 1) and are responsible for the formation of white sands covering the tablelands, slopes, mangroves, current beaches etc. In these lithostratigraphic units, the coastal tablelands are sculpted, jointly with the coastal and fluvial plains, which together constitute the three largest compartments of the relief of the studied area. The trays usually have planned tops, sometimes raised, sometimes lowered or tilted due to the evident performance of recent tectonics (FURRIER; ARAÚJO; MENESES, 2015).

In terms of sandy cover, the predominant lithologies in the area are, respectively, represented by the Barreiras Formation, which occupies a surface area of 121.38 km², which corresponds to 28.88% of the total area studied (Figure 2, Table 1).Colluvial sediments occupy 53.71 km² or 12.78% of the area and consist of material resulting from the alteration and transportation of the Barreiras Formation. The alluvial, beach and mangrove sediments together occupy 138.09 km² or 32.86% of the land. The oldest rocks outcropping in the region correspond to carbonates of Cretaceous age, with a surface of 0.48%. These outcrops occur predominantly at the bases of the slopes facing west in the municipality of João Pessoa, and when they are located in the easternmost portions, in the municipality of Santa Rita, they emerge on large surfaces at ground level (Figure 2 and Table 1). Studies claim that the limestones located in the municipality of João Pessoa belong to the Gramame Formation, whereas in the municipality of Santa Rita there are uncertainties as to whether they correspond to the base of the Gramame Formation or to the calcarenites belonging to the Itamaracá Formation (LAVOR; ARAÚJO, 2016).

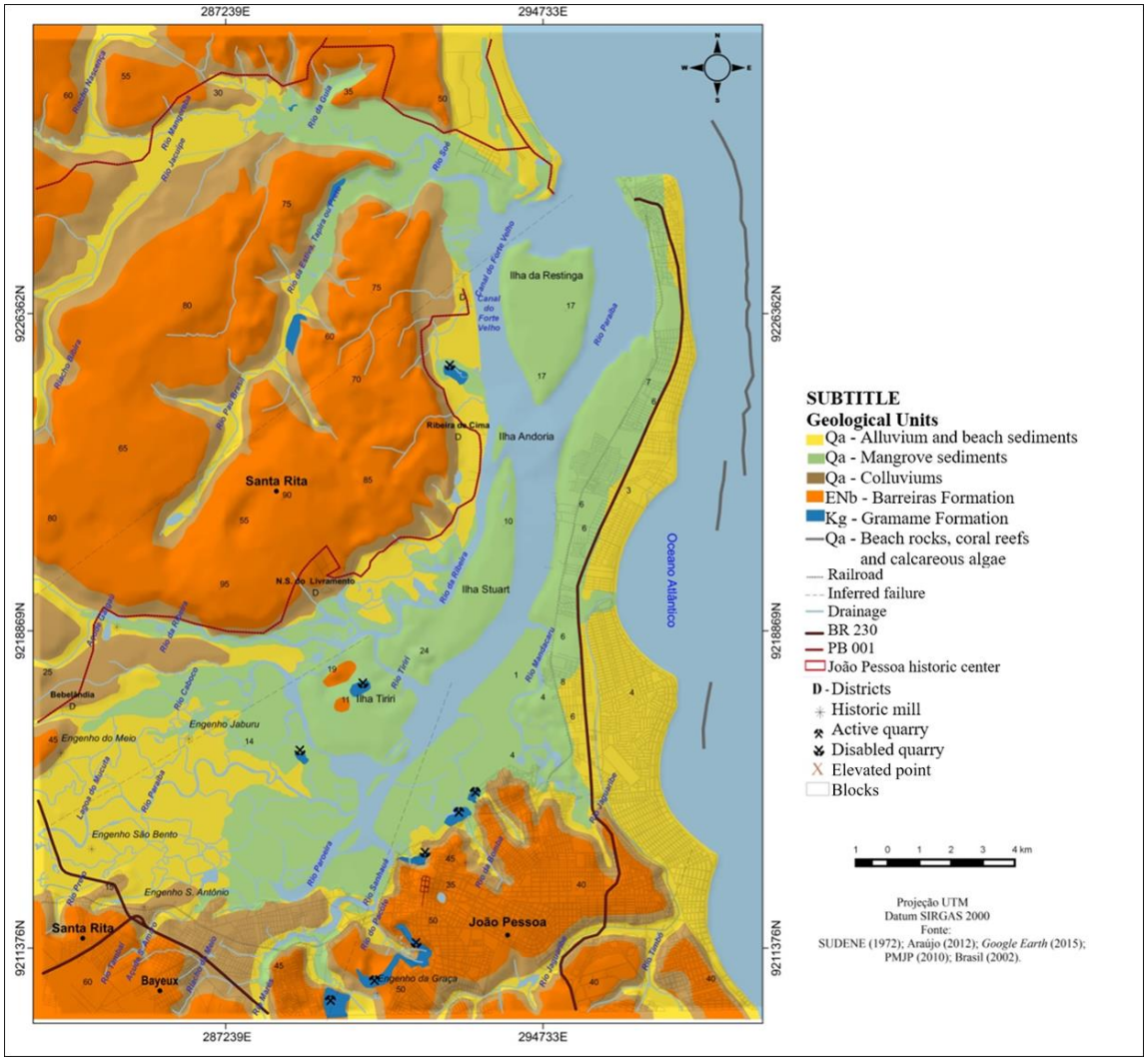


Figure 2 – Geological map of the region of the Paraíba do Norte – PB river estuary. Source: Lavor (2016).

Table 1 – Surface units of the studied area in km² and percentage. Source: Lavor (2016).

Classes	Areas in km²	Areas in %
Barreiras Formation	121.38	28.88%
Alluvium and Beach Sediments	102.46	24.38%
Colluviums	53.71	12.78%
Limestones (Gramame and Itamaracá Formation)	2.00	0.48%
Mangrove Sediments	35.63	8.48%
Reefs	11.00	2.62%
Water	94.07	22.38%
Total	**420.25**	**100.00%**

3. MATERIALS AND METHODS

The development of this work took place according to the following steps:

a) Bibliographic/documentary/cartographic review and organization of existing data: in this step, previous data were obtained, such as: publications on the geology of the Paraíba Sedimentary Basin (sedimentation, tectonics and structure) and geomorphology; geological and geomorphological map of the state of Paraíba, scale 1:500,000 (BRAZIL, 2002) available in digital media by the Executive Water Management Agency of the State of Paraíba (Aesa); geological map of the sheet SB25-Y-A-VII (Cabedelo), scale 1:100,000 (NEUMANN et al., 2014), available on the Geobank of the Mineral Resources Research Company (CPRM); Google Earth satellite images; and the topographic maps of Northeast Development Superintendence (Sudene) of 1972, scale 1:25,000, sheets: SB.25-Y-A-VI3-SE (Cabedelo), SB.25-Y-A-VI-3-SO (Soé River), SB.25-Y-C-III-1-NE (João Pessoa), SB.25-Y-C-III-1-NO (Mata da Aldeia) and SB.25-Y-C-III-1-SO (Santa Rita) (BRAZIL, 1972).

b) Previous thematic interpretations: in laboratory, the attributes to be used in the geomorphological interpretation were selected, such as contour lines, drainage and elevated points. These attributes were extracted from the previously selected topographic maps in which graphic processing techniques (punctual, linear and polygonal vectoring) were applied in a GIS environment.Then, the generation of the hypsometric model proceeded through the triangulation method. The third step was the generation of the clinographic map classified according to the Embrapa(1997) methodology.

c) Data collection in the field: through bibliographic sources and maps previously prepared in laboratory, it was possible to prepare a list of data to be investigated in the field.Data collections took place along trips to the study area, in order to identify and position the morphological elements listed in the relationship, through photographic records, creation of manual topographic profiles and acquisition of strategic points collected by a global positioning system (GPS).

d) Integration of data and elaboration of cartographic products: the geomorphological map was elaborated following the methodology for mapping by Ross (1992), with adaptations by Furrier (2007), who adjusted the methodology for areas of predominantly tabular reliefs. This methodology proposes six levels of relief units, classified as:

1st taxon: refers to the morphostructure of the sedimentary basin, which, through its structural characteristics, defines patterns of large landforms;

2nd taxon: consists of morphostructural units, formed by climatic action over geological time;

3rd taxon: corresponds to the standard units of similar landforms. It is in this taxon where the current morphoclimatic processes can be observed;

4th taxon: are the types of landforms individualized within the standard units and similar landforms. These forms can be related to processes of agradation (accumulation) or denudation. In this work, six classes of accumulation were used based on the nomenclatures suggested by Furrier (2007) for the characterization of the fourth taxon, namely: (a) area of marine terrace and plain (Atpm); (b) area of fluviomarine plain (Apfm); (c) area of river colluvium, terrace and plain (Actpf); (d) area of fluviomarinecolluvium, terrace and plain (Actpfm); (e) area of marine colluvium, terrace and plain (Actpm); and (f) area of river terrace and plain (Atpf). As for the forms of denudation, they are divided into two types: tabular and convex forms (Ross, 1992). Within them, there is a subdivision that is based on the morphometry obtained between the average interfluvial dimension and the valley's depth degree (Table 2).

5th taxon: corresponds to the individualized landforms, whose contour can be convex, rectilinear or concave. They are considered the slopes or sectors of the slopes belonging to each of the individualized landforms.

6th taxon: corresponds to smaller landforms, generated by current erosive processes or by current deposits. It is in this taxon that landforms generated by human action can be represented, such as: mining, slope cuts, among others.

Table 2 – Matrix of the dissection indexes of the landforms. Source: Adapted from Ross (1992).

Valleys' depth degree	Average interfluvial dimension				
	Very large (1) > 1,500 m	Large (2) 1,500 to 700 m	Medium (3) 700 to 300 m	Small (4) 300 to 100 m	Very small (5) ≤ 100 m
Very weak (1) < 20 m	11	12	13	14	15
Weak (2) 20 – 40 m	21	22	23	24	25
Medium (3) 40 – 80 m	31	32	33	34	35
Strong (4) 80 – 60 m	41	42	43	44	45
Very Strong (5) > 160 m	51	52	53	54	55

4. RESULTS

4.1. Relieftypes and patterns

Coastal Tablalandsreceived this designation because they present relatively flat terrain topographies. In the study area, this relief pattern has elevation levels of up to 95 m in relation to sea level. Studies point out that the microscale neotectonics that occurred in the Quaternary caused these tablelands to restructure, in order to appear as a "piano keyboard", where there are notable differences in altimetric level, associated with embedded valleys. (FURRIER; ARAÚJO; MENESES, 2015; SUGUIO, 2012).

It is possible that, due to this neotectonics, the tops of these tablelands (Figure 3) have generated forms of tabular denunciations (Dt) of three levels and forms of convex denudations (Dc) of one level, which are:

Dt31: It is observed in the João Pessoa, Santa Rita and LucenaTablelands, involving 13.31% of the study area, equivalent to 55.95 km² (Figure 3). In João Pessoa, these areas are related to altimetric levels of up to 50 m. They are large trays, relatively flat and with a little dense hydrographic network. In Santa Rita and Lucena, the Dt31 tabular landform is related to altimetric levels up to 60 m. It consists of large and relatively flat tablelands, with a small dense hydrographic network. These tablelands are quite dissected and tilted in the north-south direction.

Dt32: This landform is observed in the Bayeux tablelads, between the Marés and Preto rivers, and Santa Rita, near Santana Mill (Figure 3), occupying 10.73 km² (2.55%) of the study area. In the municipality of Bayeux, these tablelands have altimetric levels of up to 60 m, they are made up of almost flat terrains, with a small dense hydrographic network and tilted to the east. The Dt32 landform also occurs in the municipality of Santa Rita, in its rural area. It is related to altimetric levels of up to 45 m, representing the lowest tablelands in the study area.

Dt41: It is observed on the Santa Rita Tableland. This unit occupies 47.22 km² (11.24%) of the study area. Its altimetric elevations are up to 80 m, constituted from a relatively flat to semicolinous top. These tablelands are tilted to the northeast and are made up of a small dense hydrographic network with river valleys apparently developed in the fracture zones (Figure 3).

Dc31: It is located on the Santa Rita Tableland, on the right side of the source of the Pau-Brasil river until the vicinity of the Livramento district, occupying approximately 7.48 km² (1.78%) of extension (Figure 3). In this section the highest elevation of the study area is observed, which corresponds to 95 m. Both the Dt41 and Dc31 landforms are located on the Santa Rita Tableland and, due to the presence of areas that apparently suffered subsidence, they form semicircular depressions on the site.

In addition to the Coastal Tablalands, the area is also formed by plains configured as areas of accumulation or deposition of sediments. Thus, six types of accumulation were identified in the terminal portion of the lower course of the Paraíba do Norte river:

a) Accumulation area of marine terrace and plain (Atpm): It is located in the area of beach and beach ridges and occupies 31.56 km² (7.51%) of the study area, with low elevations, ranging from 0 to 8 m (Figure 3). Regarding to marine plains (Board1A), these can be classified as the areas of beaches that still suffer from the action of the waves, while the marine terraces are represented by a set of old coastlines, which, according to Suguio (1998), represent ancient coastal reliefs, located above or below the current sea level, equivalent to beach paleolines. Geographically, the Atpm landform is located in the east direction of the study area (Figure 3), more precisely on the shore the municipalities of João Pessoa; Cabedelo and Lucena (Board 1A).

b) Accumulation area of marine colluvium, terrace and plain (Actpm): It occupies 0.58 km² (0.14%) of the study area. It is the geomorphological unit of the smallest territorial extent, however, with a significant representativeness with regard to the geomorphological characterization of the coast of Paraíba (Figure 3). In this unit, the marine cliffs (active and inactive) appear, responsible for the typical landscape that forms on the beaches of the Brazilian Northeast (Boards1b and 1c). In the study area, coastal depositional processes and the constant attack of waves on the cliffs promoted their retreat to the west, rendering them inactive in some sections. Examples are the cliffs of the eastern sector of the municipality of João Pessoa, in the neighborhoods of Tambaú and Manaíra, and the Fagundes beach in Lucena.

c) Accumulation area of fluviomarine plain (Apfm): It corresponds to mangrove and sandbank areas (Figure 3) and is located in the terminal portion of the low river courses, formed by river and marine deposits. They are areas influenced by the oscillation of the syzygy tides, present from the mouth of the rivers that flow into the ocean to where the action of the tides is in effect. It is in this section of the study area that the estuary and part of CabedeloSandbank are located, with altimetric levels varying from 0 to 5m. Inside, islands are formed, to be highlighted: Tiriri, Stuart, Andorinha and Restinga (Board1d).The municipality of Cabedelo is inserted almost entirely in this geomorphological compartment, which, in consortium with the Atpm relief unit, constitutes an area of the municipality. In the municipality of João Pessoa, the Apfm relief unit occurs in the terminal portion of the rivers that flow into the Atlantic Ocean and on the Sanhauá and Mandacaru riverbanks (Figure 3). In total they occupy 40 km² (9.52%) of the study area.

d) Accumulation area of fluviomarinecolluvium, terrace and plain (Actpfm): It is located in the center-west sector of the study area (Figure 3) and occupies 21.61 km² (5.14%) of area, with altimetric levels varying from 5 to 30 m. It includes portions of the fluviomarine plain, terraces and colluviums that cover the foothills of the slopes of the Santa Rita and LucenaTablelands. It is in this environment that lagoons are formed and outcrop limestone on the left bank of the Ribeirariver. In this section, Actpfm extends for 1.5 km, from the foothill of the slope of the Santa Rita Tableland to the left bank of the Ribeira river, where the districts of Ribeira and Forte Velho are located.

e) Accumulation area ofriver terraceand plain (Atpf): This relief occupies an area of 26 km² (6.19%), with altimetric levels varying between 0 and 14 m, and consists of river plains and terraces (Figure 3 and Board1E). The river plain, also identified as a floodplain, corresponds to the shallow surface located above the average water level of the river channel, just after the marginal dikes (GUERRA; GUERRA, 2008).

f) Accumulation area of river colluvium, terrace and plain (Actpf): This morphological feature is found in consortium with Atpf and extends over almost all aspects of the coastal boards, occupying an area of 74 km² (17.61%) (Figure 3). In this region are located glacis or pediments, which project downstream with a low slope, feeding the river channels with sediment.

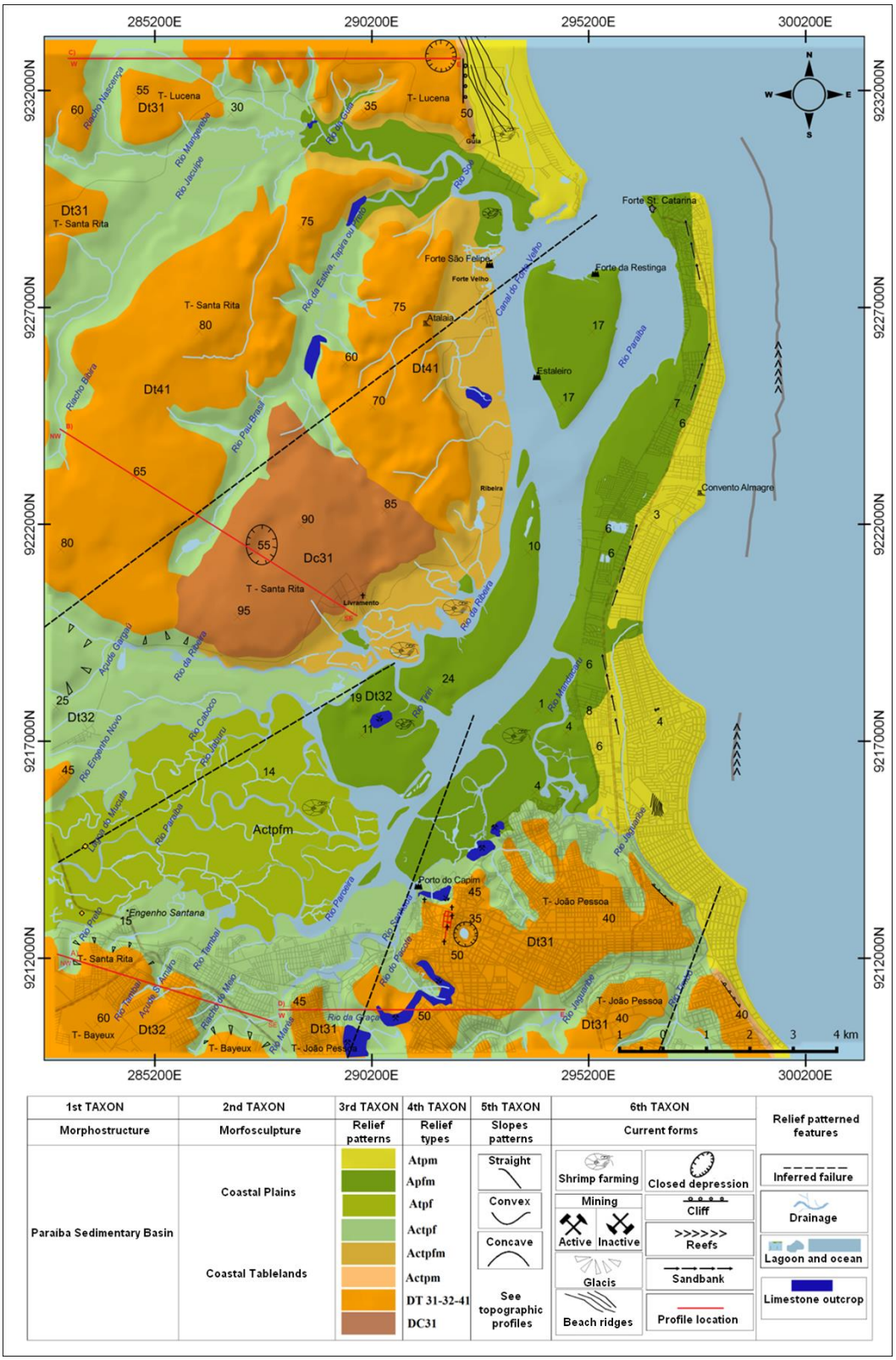
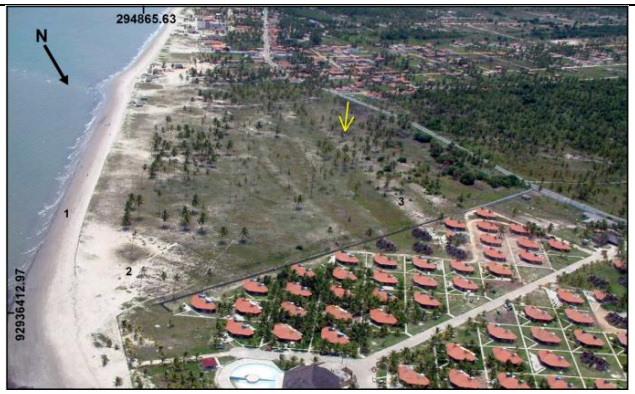
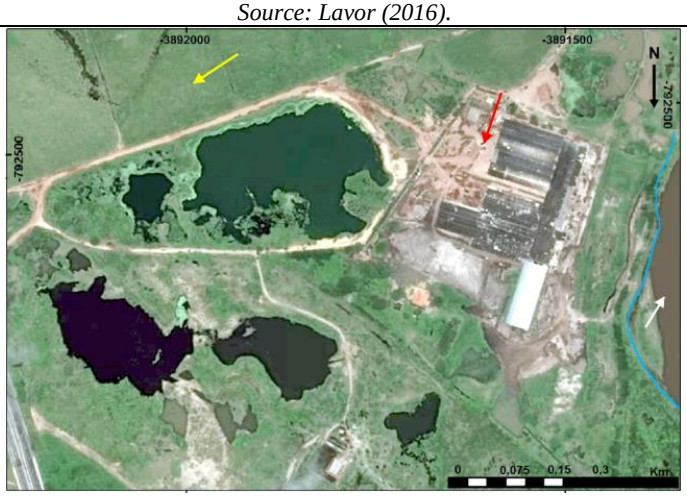


Figure 3 – Geomorphological map of terminal portion of lower course of Paraíba do Norte river. Source: Lavor (2016).

Board 1 – Types of accumulation relief present in the study area.

A) Area of marine terraces and plain (Atpm) on Ponta de Lucena beach. In the aerial photograph, part of the marine plain of the municipality of Lucena is observed, formed by the beach (1) and the Ponta de Lucenashoreface. Then there are the holocenic marine terraces (3) containing old coastline (yellow arrow) to the west of the image.	 *Source: Ricardo Paulo'scollection(2002).*
B) Inactivecliffof Cabo Branco beach (João Pessoa). In the image a cectionof the inactive cliff of Cabo Branco (yellow line) can be observed, which extends to the beach of Manaíra, to the north. The red line corresponds to the areas where colluvial sediments were deposited and which are currently overlapped by vegetation. There is also the presence of abrasion terraces (1) resulting from the erosion that occurred on the cliff, indicating its former position and the retreat of the slope to the west. The number 2 represents the Cabo Branco beach strip.	 *Source: Author's collection (2018).*
C) Active cliffof Cabo Branco beach (João Pessoa). The photo shows erosive activities on the cliff of Cabo Branco, making it naturally active (yellow line). The red lines, located between the middle and the lower slope, highlight the colluvial deposits sculpted at the foothill of the cliffs, constituting the talus. In the left part of the photo, the presence of abrasion terraces is observed (1). The yellow arrow indicates the section where the cliff is covered with vegetation, becoming inactive. The eroded wall (2) is the old courtyard of Iemajá square. Currently it is totally destroyed by the actions of the coastal dynamics.	 *Source: Author'scollection (2013).*
D) Apfm of the Paraíba do Norte river estuary. In the center of the photo is the Restingailandformed by sediments of transitional origin (continental-oceanic). The blue polygon corresponds to a fluviomarine beach of recent origin. In the western sector of the image, the Santa Rita Tableland (yellow line) can be seen. In this section (1) is located the area of colluvium (red lines), fluviomarineterrace and plain (Actpfm), where limestones outcrop.	 *Source: Ricardo Paulo'scollection(2002).*

E) River terrace (yellow line) located on the left bank of the Paraíba do Norte river, close to BR 230, in the municipality of Santa Rita. The terrace has a uphill of approximately 4 m.	 *Source: Lavor (2016).*
F) Actpf of the terminal portion of the Paraíba do Norte river (Santa Rita). The yellow arrow indicates the river plain, currently used for planting sugarcane; the red arrow indicates the structure of a pottery; the white arrow corresponds to a meander of the Paraíba do Norte river; the semicircular forms filled with water refer to technogenic-degradational landforms, related to the extraction of clay for the manufacture of tiles and bricks; the blue line corresponds to the river terrace of the river.	 *Source: adapted from Google (2015).*

4.2. Patterns and types of slopes

Considering the processes responsible for sculpting the hillsides of the tablelands, two groups of slopes can be highlighted: the cliffs, where the continental and marine dynamics complement each other in their sculpting; and the slopes of the river valleys, where continental dynamics play a dominant role. To better illustrate these aspects, topographic profiles of the study area were elaborated. These profiles allowed to characterize sections of these hillsides (Figure 4).

Through field observations, it was found that the slopes located in the municipality of Bayeux (Figures 3 and 4a) are of the type: convex-rectilinear and rectilinear-convex, forming valleys with a concave bottom, in the Preto river; embedded and asymmetrical, with straight-convex slope on the left bank and straight-concave on the right bank of the Tambaí river; and asymmetrical, in the Meiostream, with a convex-rectilinear slope on the left bank and rectilinear-concave on the right bank.

In the municipality of Santa Rita, it is verified that the forms of slopes (Figures 3 and 4b) present patterns of the type: convex-rectilinear, on the left bank of the Jacuípe river; valley in V, at the source of the Estivariver; flat-bottomed valley, with convex-rectilinear slopes, on the Pau-Brasil river; and convex-rectilinear slopes, on the hillside of the left bank of the Ribeirariver.In addition to the river valleys, this profile had two landforms on the surface of the tableland. The first consists of a small hill in the form of a plateau (small plateau), located between the Jacuíperiver and the source of the Estivariver; and the second corresponds to a closed depression, located between the Pau-Brasil river and the Ribeira river.

In the municipality of João Pessoa, between the slope on the right bank of the Marésriver and the slope on the left bank of the Jaguaribériver, convex-rectilinear hillsides were observed in the field, which shows forms of relief of the plateau type. The flatness of this tableland is interrupted by the depthof the Graça river and the exploitation of limestone in the open pit mine, located in the Mechanical District of the Trincheiras neighborhood (Figures 3 and 4d).

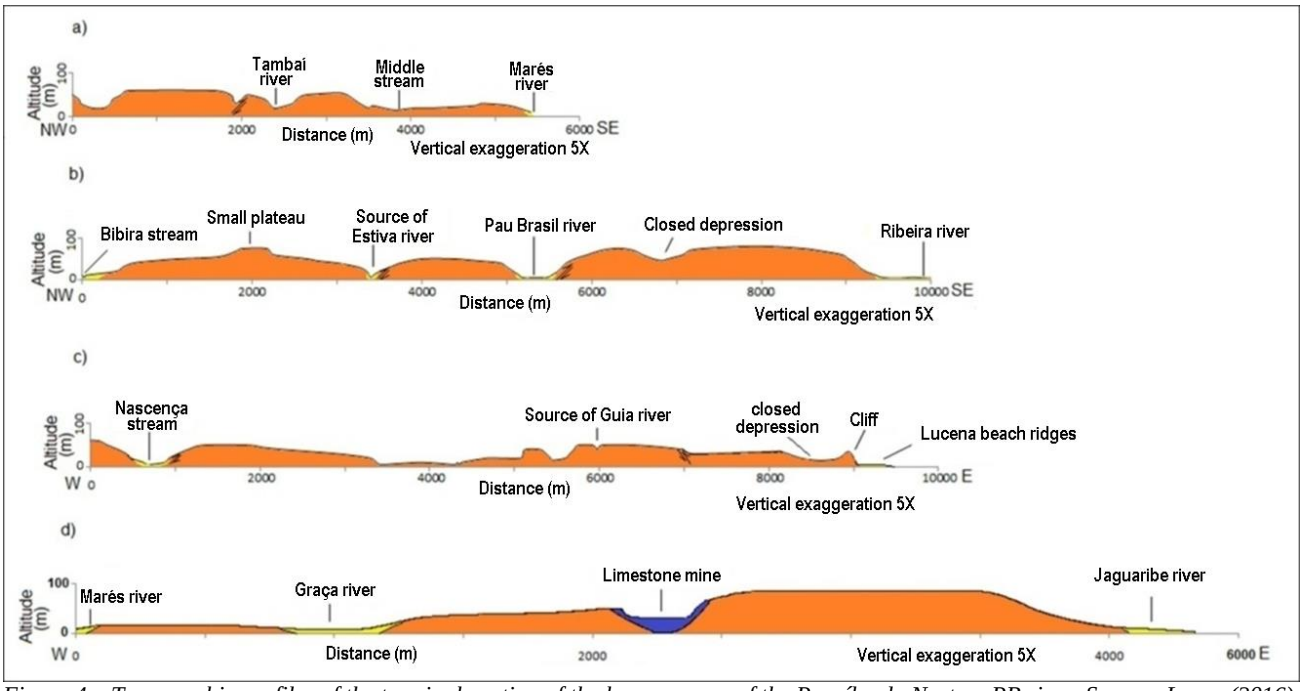


Figure 4 – Topographic profiles of the terminal portion of the lower course of the Paraíba do Norte – PB river. Source: Lavor (2016). Note: (a) topographic profile of Coast Tableland in the municipality of Bayeux; (b) topographic profile of Coast Tableland in the municipality of Santa Rita; (c) topographic profile of Coast Tableland in the municipality of Lucena; (d) topographic profile of Coast Tableland in the Municipality of João Pessoa. Observe the locations of the profiles in Figure 3 (red line).

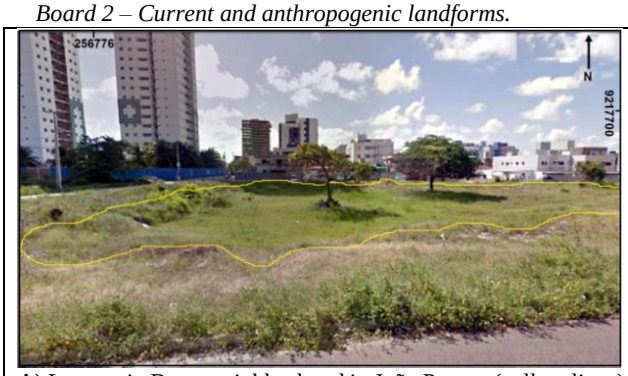
4.3. Other landforms (current forms)

a) Anthropogenic lagoons and ponds: The lagoons are commonly found in marine and fluviomarine plains, such as the one in Cabedelo (Figure 3). They correspond to the depressions that occur in these plains and that, in the rainy season, store water from the outcropping water table. Due to the intense urbanization process that this plain faces today, most of these lagoons were buried, leaving only one specimen (Board 2A), located in the Bessa neighborhood (João Pessoa). In addition to the natural lagoons, there are also, in the Cabedelo plain, lagoon forms generated by human action, such as the ponds of Jacaré beach (Cabedelo), generated due to the sand extraction activity for civil construction (Board2B).

b) Sandy banks of coastal reefs: In the surf zone of the beaches of the municipality of Cabedelo, there are rocky formations called coastal reefs (Figure 3). It is on this stretch that sandbanks, known locally as AreiaVermelhad and AreiaDourada, emerge at low tides. They are accumulations of sediments in the shape of a "crown", possibly developed by the fronts of waves when they affect the reefs. According to Miranda (2005), the sediments that compose these banks are made up of fine and medium grains of sand associated with gravel fragments of organic origin (such as gastropod shells and fragments of limestone algae), which accumulated due to the currents that circulate between the reefs and the region's beach. Currently, these sandbanks are located within the limits of the Conservation Unit (CU) AreiaVermelha Marine State Park (PEMAV), which occupies an area of 2.3 km², 1 km away from Camboinha beach, in Cabedelo (Boards2C and 2D).

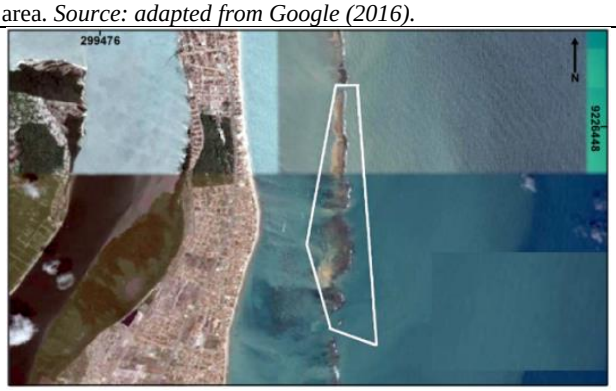
c) Barra de Cabedelo: For years, there have been significant changes in the morphology of the coastline of the mouth of the Paraíba do Norte river. Guedes (2002) found that, at the tip of the Cabedelofluviomarine plain, where the port complex and the Santa Catarina fort are located, there was a progradation of the coastline to the north of approximately 300 m. Probably, the construction of the port of Cabedelo and, later, of a pier (1,200 m long) perpendicular to the coastal drift, interfered with the local morphodynamics. The opposite occurred in the marine plain of Lucena, where there was an intense erosion process.The construction of the pier on the south side of the mouth led to the erosion of the Ponta de Lucena beach (Costinha beach). With the purpose of containing these processes and, at the same time, promoting the fattening of this beach, gabions were installed on the Costinha beach (Board2E), which generated the deposition of sediments inside the estuarine channel, providing the formation of dunes and the progradation of the frontal portion of the Restingaisland (GUEDES, 2002). The coastal dynamics itself promotes changes in these areas and, when they suffer anthropogenic interferences, the processes intensify and, when analyzing the satellite image of 2015 (Board2F), new changes in the morphology of the bar are observed. It was found that, from the port complex to the beach, there was aorif=gradation of approximately 300 m more than that observed by Guedes (2002).

Board 2 – Current and anthropogenic landforms.



A) Lagoon in Bessa neighborhood in João Pessoa (yellow lines). Apparently, it is silted up and surrounded by a very urbanized area. *Source: adapted from Google (2016).*

B) Ponds of anthropogenic origin generated by the activity of mineral extraction for civil construction (yellow lines), located at Jacaré beach (Cabedelo). *Source: adapted from Google (2016).*



C) Delimitation of the PEMAV (white polygon). In the image, the sinuosity of the reef environment that is parallel and almost the same shape as the current coastline of the municipality of Cabedelo is evident. This observation leads to the understanding that this geomorphological form is possibly a coast paleoline. *Source: adapted from Google (2015).*

D) Sandbar located in the PEMAV, at a 0.7 m tide. Calcareous algae, regoliths, corals and other marine species that emerge in tides from 0.5 m proliferate around the bank.. *Source: Lavor (2016).*

E) Aerial photography where are observed various engineering constructions of pier type (1) on Costinha beach (Lucena). To the northwest of the image are the Santa Rita Tableland (yellow line), a section of the accumulation area of colluvium (red lines), fluviomarine terraces and plains (2) in Forte Velho district (Santa Rita) and part of the accumulation area of fluviomarine plain of Lucena. *Source: Ricardo Paulo's colection(2002).*

F) The dashed areas were those have changed, in red are those of progradation and, in yellow, sectors in process of erosion. *Source: adapted from Google(2015).*

(d) Closed depressions

The closed superficial depressions correlated to the limestones of the Paraíba Sedimentary Basin are geomorphological units that can occur with or without the presence of water. Observation in the field and subsurface data evaluated by Lavor (2016) points out that the closed surface depressions are related to the slow subsidence dolines present in the limestone rocks lands under the Barreiras Formation.Three superficial closed depressions in the area were identified. The first is located at the top of the Coastal Tableland of the municipality of João Pessoa, has a centripetal radial basin with an area of about 1.0 km² and a perimeter of about 4.0 km (Figure 5-1). The second is located in the municipality of Santa Rita and has an oval outline, diameter of 0.52 km and perimeter of 2.92 km (Figure 5-2). The third is located in the municipality of Lucena and has a circular shape, diameter of 2.66 km and perimeter of 0.54 km (Figure 5-3).

Figure 5 – Closed depressions (dolines). Source: self elaboration adapted from Google (2015).

5. CONCLUSIONS

The results of the various analyzes carried out in this research showed a clear relationship between geology, through lithological and tectonic aspects, and climatic conditions, which favored the formation of reliefs and rivers that shaped the coastal surface, giving rise to the plains, terraces, depressions and elevations of almost flat tops. Coastal dynamics also participated in the modeling of the region, contributing to the formation of marine terraces, cliffs, beach ridges, beaches and estuarine areas.

Much of the studied area is highly urbanized, especially those related to the Atpm and Apfm relief units, which are geomorphologically unstable regions due to the degree of dynamism caused by the influence of tides, waves and wind, as well as chemical and biologicalfactors. As they are zones of sediment accumulation with a natural tendency in certain sectors of the beaches to present a sedimentary deficit, these areas need greater attention from management agencies, due to their high vulnerability.Another highly altered area is related to the Actpf unit. In the southern sector of the study area, these forms of accumulation are highly urbanized, while in the west they are related to the cultivation of sugarcane. This unit is located between the slopes and the denudational areas of the Coastal Tableland and drains water from the Barreiras aquifer into it, which migrates through resurgences at the foothills of the slopes, allowing dissection and outcropping, in some sections, of the Gramame Formation. It is in these sectors that the limestone rock mining areas are located.

It is concluded, therefore, that understanding the geomorphological picture of the coast of Paraíba is an important step for the management of its urban and rural areas. The techniques applied in the elaboration of the cartographic products of the present work made it possible to produce an unprecedented geomorphological map for the study area. Therefore, these data can be used as a basis for the elaboration of works related to the territorial planning and ordering of the terminal portion of the lower course of the Paraíba do Norte river.

6. REFERENCES

ALHEIROS, M. M.; LIMA FILHO, M; MONTEIRO, F. A. J; OLIVEIRA E FILHO, J. S. Sistema deposicional na Formação Barreiras no Nordeste Oriental. In: BRAZILIAN CONGRESS OF GEOLOGY, 35, 1988, Belém. *Proceedings [...]*Belém: SBG, 1988. v. 2, p. 753-760.

BARBOSA, T.; FURRIER, M.; SOUZA, S. A. Antropogeomorfologia do município de Cabedelo – Paraíba, Brasil. *Revista de Geografia eOrdenamento do Território*, ano 13, p. 59-83, 2018.

BRAZIL. Brazilian Institute of Geography and Statistics. Coordination of Natural Resources and Environmental Studies. *Manual Técnico de Geomorfologia*.2. ed. Rio de Janeiro: IBGE, 2009.

BRAZIL. Ministry of Mines and Energy. Mineral Resources Research Company – Geological Survey of Brazil. *Geologia e recursos minerais do estado da Paraíba.* Recife: CPRM, 2002. 142 p. il., 2 mapas. Escala 1:500.000, 2002.

BRAZIL. Northeast Development Superintendence. *Folhas SB.25-Y-A-VI-3-SE (Cabedelo), SB.25-Y-A-VI-3-SO (Rio Soé), SB.25-Y-C-III-1-NE (João Pessoa), SB.25-Y-C-III-1-NO (Mata da Aldeia) e SB.25-Y-C-III-1-SO (Santa Rita).* Recife: Sudene, 1972. 5 Cartas Topográficas. Escala 1:25.000, 1972.

CHRISTOFOLETTI, A. *Geomorfologia*. 2. ed. São Paulo: Edgard Blucher, 1980.

CORREA FILHO, O. J; ALENCAR, M. L; BARBOSA, J. A; NEUMANN, V. H. Proposta de formalização da formação Tambaba, Eoceno da bacia Paraíba, NE do Brasil. *Estudos Geológicos*, v. 25, n. 2, p. 61-81, 2015.

EMBRAPA. Brazilian Agricultural Research Company. NationalSoilResearch Center. *Manual de métodos de análise de solo.* 2. ed. Rio de Janeiro: Embrapa, 1997.

FURRIER, M. *Caracterização geomorfológica e do meio físico da Folha João Pessoa – 1:100.000.*2007. 213 p. Thesis (Ph.D in Physical Geography) –University of São Paulo, São Paulo, 2007.

FURRIER, M; ARAÚJO, M. E; MENESES, L. F. Geomorfologia dos Tabuleiros Litorâneos no estado da Paraíba. In: SILVA, A. B; GUITIERRES, H. E. P; GALVÃO, J. C (Orgs). *Paraíba:* pluralidade e representações geográficas. Campina Grande: EdufCG, 2015.

GOOGLE. *Google Earth.* Available at: https://www.google.com.br/earth. Access on: Aug. 26, 2015.

GOOGLE. *Google Maps.*Avaliable at: https://www.google.com.br/maps. Access on: Oct. 10, 2016.

GUEDES, L. S. *Monitoramento geoambiental do estuário do rio Paraíba do Norte – PB por meio da cartografia temática digital e de produtos de sensoriamento remoto.*2002. 91 p. Dissertation (Master degree in Geodinamics and Geophysics) –Federal University of Rio Grande do Norte, Natal, 2002.

GUERRA, A. T.; GUERRA, A J. T. *Novo dicionário geológico-geomorfológico.* 6. ed. Rio de Janeiro: Bertrand Brasil, 2008.

LAVOR, L. F. *Geodiversidade e sítios históricos na porção terminal do baixo curso do rio Paraíba do Norte.*2016. 174 p. Dissertation (Master degree in Geography) – Federal University of Paraíba, João Pessoa, 2016.

LAVOR, L. F.; ARAÚJO, M. E. Afloramentos calcários e antigas pedreiras no estuário do rio Paraíba do Norte – PB. *Estudos Geológicos (UFPE),* v. 26, p. 46-61, 2016.

MARQUES, J. M. Ciência Geomorfológica. In: GUERRA, A. J. T.; CUNHA, S. B. Geomorfologia: uma atualização de bases e conceitos. 7. ed. Rio de Janeiro: Bertrand Brasil, 2007. p. 23-45.

MAIA, R. P.; BEZERRA, F. H. R. Geomorfologia e neotectônica da bacia hidrográfica do rio Apodi-Mossoró – NE/Brasil. *Mercator*, v. 11, n. 24, p. 209-228, jan./abr. 2012.

MIRANDA, G. E. C.(Org.).*Relatório do grupo de trabalho para ampliação do Parque Estadual Marinho Areia Vermelha (Cabedelo-PB).* João Pessoa: EdUFPB, 2005.

NEUMANN, V. H. M. L.; GUERRA, N. C; MELO, C. B.; FARIAS, D. J. S.; MENESES FILHO, J. A.; LIMA, F. P. 2014. *Carta geológica da folha SB.25-Y-A-V II Cabedelo*, escala 1:100.000. Brasília: CPRM, 2014.

RODRIGUES, S. C.; OLIVEIRA, P. C. A. Cartografia do relevo: um estudo aplicado na região oeste de Minas Gerais. *Revista Brasileira de Geomorfologia*, year 8, n. 2, p. 37-44, 2007.

ROSS, J. L. S. *Geomorfologia Ambiente e Planejamento: O relevo no quadro ambiental cartografia geomorfológica, diagnósticos ambientais*. 9. ed. São Paulo: Contexto, 2014

ROSS, J. L. S. O registro cartográfico dos fatos geomórficos e a questão da taxonomia do relevo. *Revista do Departamento de Geografia (USP)*, São Paulo, n. 6, p. 17-29, 1992.

SOUZA, J. O. P. Análise da precisão altimétrica dos Modelos Digitais de Elevação para área semiárida do Nordeste brasileiro. *Revista do Departamento de Geografia*, USP, v. 30, p. 56-64, 2015.

SUGUIO, K. *Geologia do Quaternário e mudanças ambientais.* São Paulo: Oficina de Textos, 2012.

SUGUIO, K. *Dicionário de Geologia Sedimentar e áreas afins*. Rio de Janeiro: Bertrand Brasil, 1998.

Received in: 02/09/2019
Accepted for publication in: 23/08/2020