RESEARCH PAPER

SEDIMENT DYNAMICS IN LACUSTRINE ENVIRONMENTS — NORTHERN AMAZON

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ABSTRACT. Lakes are features found in Brazil's northern region, commonly formed in sandy-clay layers of the Plio-Pleistocene, in a setting of the extensive flat surface, and under a high precipitation rate. Our goal in this work is to understand the sediment transport dynamic and its relation to the hydrological behavior of the regional lacustrine system. Two lakes were selected, Lago do Italiano (LIT) and Lago do Bicho (LB), situated in the municipality of Bonfim in the state of Roraima, Brazil. The lakes differ in hydrological regime, depth, and vegetation. The methodology involved bibliographical and remote sensor data and field surveys followed by laboratory processing. The results revealed that the lakes are composed of sandy materials, with layers what reach 95% of sand. The grains is medium to fine texture, with morphology angular (0 a 50%) and subangular (18% a 43%) grains, disposed at different depths. The grains' morphology suggests that their sediment provider source is near and, at the same time, indicates a low energy environment. Concerning the mineralogical attributes, the sediments are of a quartzose nature, which permits their correlation with the arenites of the Boa Vista Formation, a sub-cropping unit. The sediment input is controlled by the seasonal oscillation of the groundwater level and inundation pulses that reach the fluvio-lacustrine plain of the Tacutu River in which the lakes are inserted.

KEYWORDS: aquatic ecosystem, hydrological regime, sediment provenance, Amazonian lakes

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INTRODUCTION

The great diversity of formation processes of lake basins, such as the geological phenomena that act jointly or in isolation, causes the lakes to be common to different landscapes on the terrestrial surface. The lacustrine genesis generally links these features to glacial, volcanic, and tectonic environments, and its dynamics are related mainly to the fluvial and coastal processes. The lake basin development is reflected in the sediment compositions, made up of different materials from primary and secondary structures and with great variety in size, shape, and chemical composition.

These materials may come from autochthonous sources, such as those formed from the lake's own debris, originating mainly from herbaceous plants and plankton, deposited after dying, or from allochthonous sources, materials transported beyond their source area and later deposited in the lakes, carrying important information about the drainage basin to which they are integrated (Murdoch and Macknight 1994; Vonk et al. 2016).

The lakes are also considered to be sources of greenhouse gasses, resulting, amongst other factors, from the anaerobic degradation of the vegetal biomass, mediated by microorganisms acting according to the thermal stratification of the water column (Zdorovennova et al. 2016). In this scenario, the sediment-lake interface is of special interest to studies on climate change on different scales, due mainly to anthropic disturbances that have been observed, such as bad soil use, erosion, and siltation problems, reflecting the conditions of use and occupation of the lake (Cardoso et al. 2019).

Throughout the lakes' evolution, sediment layers are formed, containing chemical composts along with biological structures, representing the different phases of the process (Moiseenko et al. 2012). Thus, the sediments' capacity at accumulating composts is also responsible for turning this compartment into one of the most important for analyzing contamination levels of the aquatic environments since most of the fresh, liquid, and surface water on which humans depend is located in only a few lake basins (Meneses et al. 2007; Bootsma 2018).

In this light, understanding the lake sediment attributes is essential, considering that the flow and drainage dynamics interfere directly in the pedogenetic processes. Additionally, these studies help keep regular information about chemical element concentrations that may constitute a source of lake environment pollution, e.g., aluminum used in wastewater treatment and barium coming from insecticides (Maia et al. 2006). A study by Xu et al. (2017) in 110 lakes in China described the pollution of sediments by heavy metals, including cadmium, which is a highly toxic metal used, mainly in the manufacture of batteries.

That said, knowing the properties of lake sediments allows us to identify important historical records of events that occurred in the depositional environment, essential

for the evolution and dynamics of the drainage basin, as well as for predicting scenarios for the recovery of these ecosystems. In Amazonia, systematic investigations of lake sediments have focused on the reconstruction of environmental changes in the late Quaternary; for example, the record of sediments dominated by organic material interspersed with debris indicate fluctuations in lake levels related to changes in humidity conditions and levels of precipitation in the region (Costa et al. 2005; Guimarães et al. 2016; Fassoni-Andrade and Paiva 2019).

Studies facing lacustrine environments in Roraima have been directed mainly to the state's eastern portion. Amongst them stand out works emphasizing ecological change (Simões Filho et al.1997); physiographic (Meneses et al. 2007); morphological and morphometrical (Pinheiro and Jardim 2015). Evidence of environmental transformation, pointed out by Santos Neto et al. (2013), promoted mainly by anthropic occupation at the lakes' natural limits, along with the morphogenetic approach of Alves and Beserra Neta (2018).

In this approach, the authors considered that the main responsible morphogenetic principles for the installation of the lakes are intimately linked to the condition of the predominantly plane relief, associated with the humid climatic conditions and the sandy-clay sediment cover of the Boa Vista Formation. In this sense, these lakes' spatial distribution derives from the relationship between the factors mentioned above and the local climatic regime, which affect the groundwater level variations. These factors result in the occurrence of the majority of the lakes in specific locations of which the gradient is concentrated in the inundation areas of the region's main rivers.

So far, the Northern Amazon lakes have been contemplated by studies approaching their diverse natural and anthropic aspects. However, aspects of their sediments in a refined scale remain poorly understood. Thus, the effort of this study is to support future limnological reconstitutions, since these lakes are already showing signs of degradation (Alves and Ribeiro 2018), having as its objective an understanding of the sediment transportation and depositing dynamics and the possible relation with the hydrological behavior of the regional lacustrine system, using as indicators the morphological, granulometric, mineralogical and chemical aspects of the superficial grains.

Two lakes were selected, differing in their hydrological regime, depth, and vegetation that adapts according to the presence of the water sheet. Such factors grant different answers to the characteristics of the sediment transport dynamics. In terms of environmental conditions, these lakes represent the reality of many northern Amazon lakes due to the environmental implications they are subjected to through the increase in urban occupations on their riverbanks.

MATERIALS AND METHODS

Study Area

The study area is located in the Bonfim municipality, east of the Roraima State, north of Brazil. The lakes investigated in this study are situated in this stretch: the *Lago do Italiano* (LIT) and the *Lago do Bicho* (LB), the former representing an intermittent regime, the latter perennial (Fig. 1).

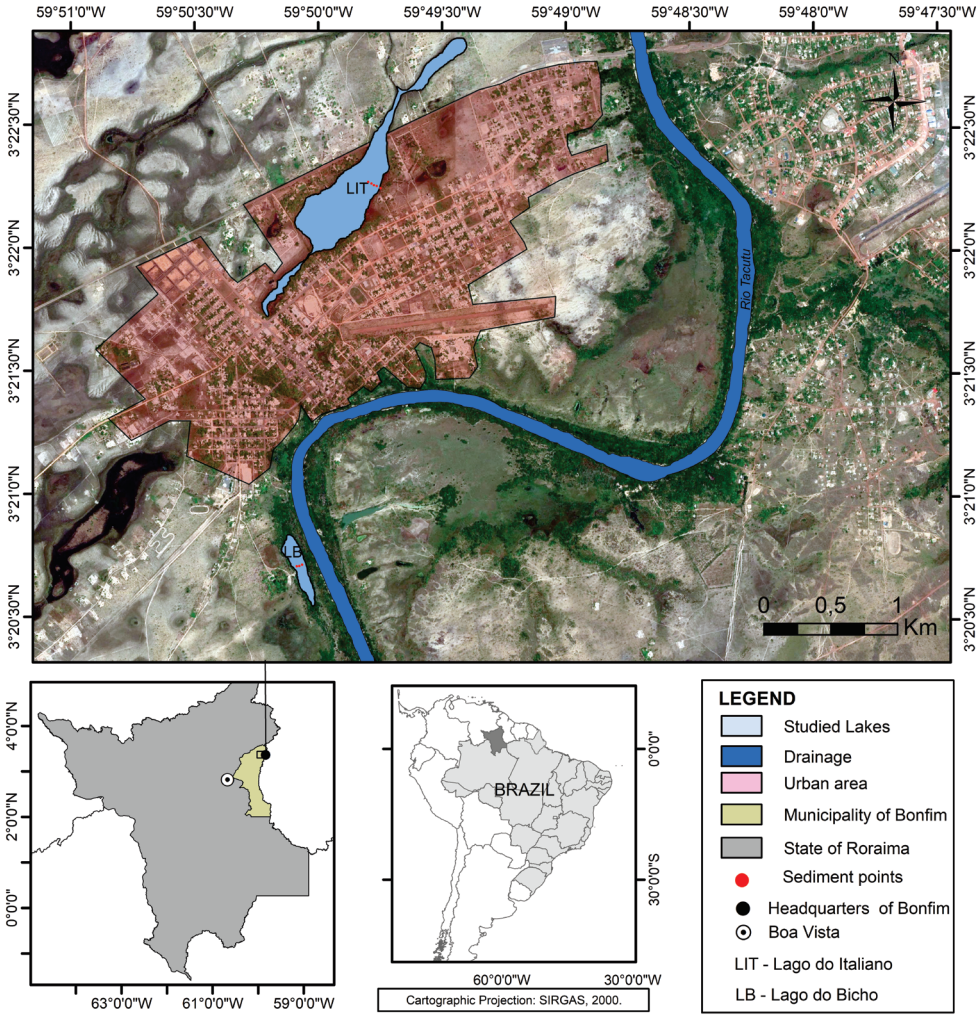

Fig. 1. Location of the study area with the Lago do Italiano (LIT) and the Lago do Bicho (LB), Roraima, Brazil

The geological terrain integrates the Cenozoic covers that comprise the lithotypes conglomeratic and arcosian sandstone and siltstone, grouped in the Boa Vista Formation, of Pliocene age, and recent alluvial deposits constituted of gravel, sand, and semi consolidated and unconsolidated clay (CPRM 2009). The area is inserted in a fluvial-lacustrine plain in the morphostructural domain Pediplano Rio Branco — Rio Negro (Franco, Del'Arco and Rivetti 1975), presenting plane features, gently undulating patterns with low altitudes.

The lithology is closely related to the region's soil types, predominantly oxisols, gleysols, and entisols (quartzipsamments). The first is distributed in the savannah, found on the plains, while the others are more predominant along the valley bottoms and tributaries of the river Tacutu (Melo et al. 2010).

The climate is tropical with dry and wet seasons, type "Aw" of the Köppen classification, having rainfall concentrated in the period May through August, and the dry season from September through April. The mean annual temperature is 27°C, with a rain index varying between 1,400 and 1,700mm yearly (Barbosa 1997).

The landscape is dominated by savannahs, composed of graminoid strata permeated by small arborescent species, spaced out or grouped, consisting of palm trees surrounding the aquatic ecosystems, thus forming the physiognomical mosaic of the region.

Procedure

The present study was guided by a survey of bibliographical, remote sensors, field, and laboratory data. In the field campaign, 23 lake sediment samples were collected in a sequential mode, considering vegetation, slope, and pedological gradient (Fig. 2). Vegetation was identified from field recognition and visual comparison of taxonomic data contained in Amaral et al. (2008) and Lorenzi (2017).

The sediment samples were subjected to granulometric analysis in two stages: the first was the separation of the sand, silt and clay fractions (aqueous method), the second was the separation of the sand fractions (dry sieving method) according to EMBRAPA (2018).

To separate the sand, silt, and clay fractions, 100 g of samples were placed in a beaker and added to 400ml of water, placed in a Unique brand ultrasonic washer, and stirred with the help of a glass rod for 10 minutes. In this process, the washer emits vibrations that allow the heaviest particles to remain at the bottom of the beaker, in this case, the sand, leaving the silt and clay in suspension. The process was repeated a few times until the water in the beaker looked clear and showed only the sand fraction. After disaggregation, the sand was left to dry at ambient air temperature.

The silt and clay were reserved for separation, which was carried out in a CentriBio® benchtop centrifuge. Inside the centrifuge, the samples were placed in test tubes that, when rotating for 2 minutes (Repetition Per Minute/1000), the silt fraction (solid) was deposited at the bottom of the container, while the clay fraction remained in suspension. After separation and drying, the fractions were weighed separately, which allowed the determination of the percentage between the sand, silt, and clay fractions. In each fraction, the values obtained in grams were statistically treated according to Folk and Ward (1957). The distribution of samples in granulometric classes was processed in SysGran 3.1 and demonstrated in triangular diagrams by Shepard (1954).

For sand separation, a set of Tyler series sieves was used with openings of 1.00mm, 500µ, 250µ, 125µ, 63µ,

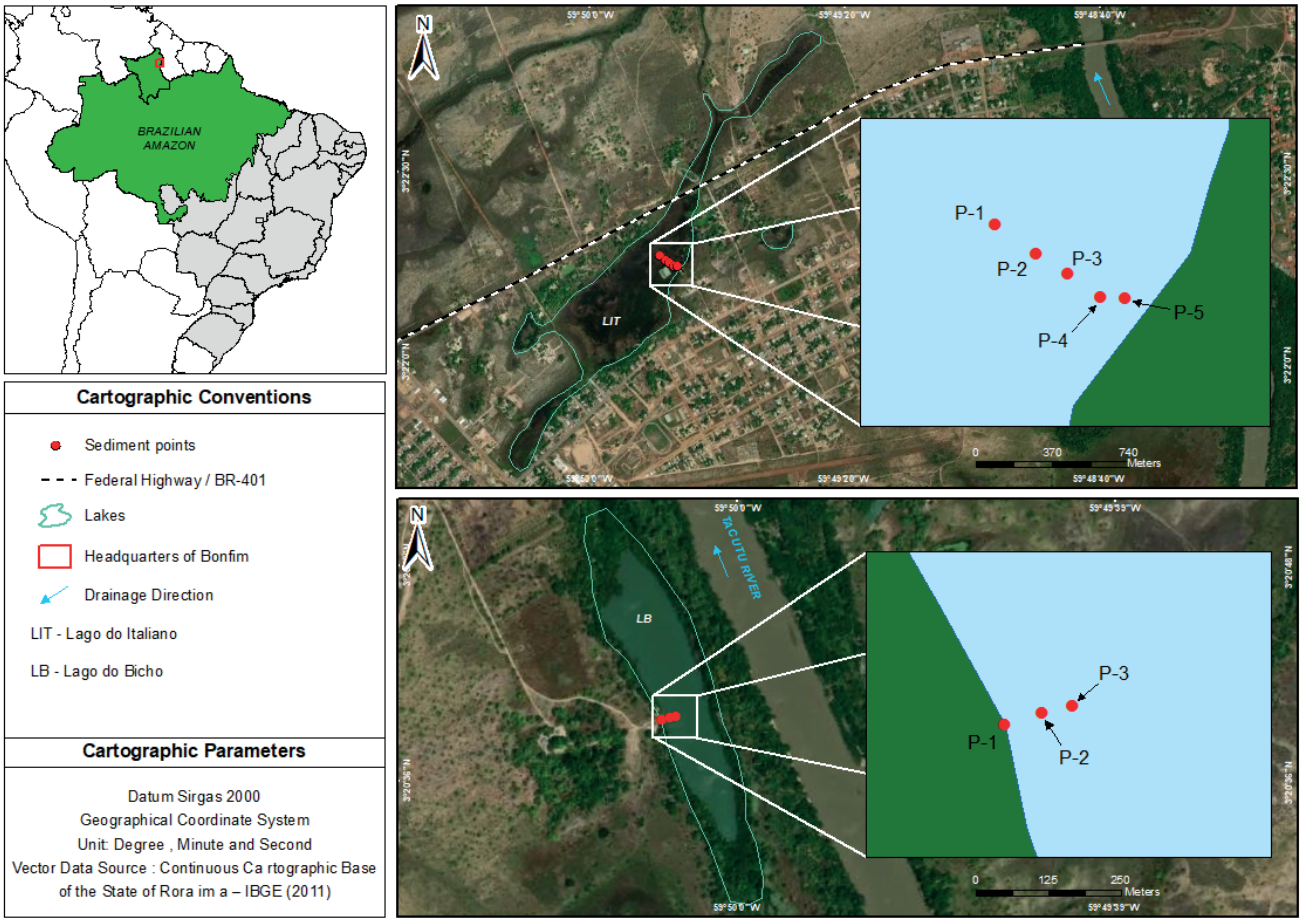

Fig. 2. Collection site in the Italiano (upper quadrant) and Bicho (lower quadrant) lakes

<63µ, superimposed in descending order placed in a mechanical shaker of the Bertel brand for 5 minutes. Upon sieving, the subfractions retained on each sieve were weighed separately, providing the necessary data for the constitution of histograms representative of their distribution in the samples. In the classification of the sediments in coarse, medium, and fine sand, the scale was used A. S. T. M. (American Society for Materials) being represented through of graphic.

The morphological analyzes of the sand grains were performed to determine the degree of roundness and sphericity of the sand grains. For this analysis, samples containing 100 grains of sand were separated and visually compared in a lupa binocular with a table of the degree of roundness mentioned by Suguio (1973). The measure of the degree of roundness for each grain is dependent on the roughness of the outer surface of the grain (perimeter) and gives the result between 0 and 1. The morphological classification being angular (0 - <15), subangular (0.15 - 0.25), rounded (0.25 - 0.40), subrounded (0.40 - 0.60) and well rounded (0.60 - 1.00).

The mineralogical identification was obtained through x-ray diffractometer, whose reading of the sample was analyzed in the scanning range of 5° to 70° 2θ (Theta), lasting 40 minutes (EMBRAPA 2018). The X'PertHighScore software was used to interpret the diffractogram peaks.

For the acquisition of high-resolution images of the sediments, a small number of grains was deposited on a carbon adhesive and inserted into the sample holder of the Scanning Electronic Microscope (SEM) model Hitachi TM3030, the scale varied from 20µm to 1mm, which allowed the detailed analysis of sediment morphology. Subsequently, punctual analyzes of the chemical composition of the grains were carried out by Energy Dispersive Spectrometry (EDS), and the percentage of chemical elements was acquired by linear mapping (single grain method).

RESULTS

Plant physiology of the lake environments

Located in the urban region of Bonfim, the Lago do Italiano, occupying an area of ~3.750m^2, is a system with a drainage flow connection pattern, presenting stretches of different width and elongated morphology. The hydrologic regime is intermittent, while in the driest period of the year, the absence of rain associated with the lowering of the groundwater level favors rapid evapotranspiration, leaving the lake's basin exposed. During the rainy season, the lake becomes intensely colonized by emerging aquatic macrophytes, mainly reed (Juncus effusus), besides colonization of adapted species, occurring in lower numbers, such as fixed nymphaeaceous macrophytes with floating leaves, capable of colonizing both shallow and deeper environments. The landscape surrounding the Lago do Italiano is characterized by an arboreal plant cover, concentrated at the eastern bank of the lake basin and one more herbaceous vegetation concentrated at its western bank.

The Lago do Bicho, in turn, occupying an area of 531m^2, is a lake of lateral accretion, with an elongated shape and NW-SE orientation, formed along the right bank of the river Tacutu.

During the wettest periods, this lake receives large amounts of sediments. Situated in the Tacutu flood plain, the lake undergoes a perennial regime, presenting significant depth as compared to the Lago do Italiano. Because of its depth, vegetation is restricted to the lake's margins. Furthermore, the settlement of species is modified according to the altimetry of the area. In this respect, arboreal densification (Genipa americana) occurs intermingled with isolated palm species (Astrocaryum aculeatum). In the intermediate area, on the other hand, bordering the water sheet, fixed macrophytes with floating stalks appear (Montrichardia arborescens), these in turn being adapted to the ecotone conditions of lacustrine environments and hydromorphic environments at the valley bottoms, influenced mainly by slope and water level variations.

Sediment characterization and its relation with transportation dynamics and lake deposits

According to Shepard Classification, the sediments have a predominance of sand texture, followed by silty sand and clayey sand, with texture variation in the intervals throughout the sampled sequence (Fig. 3). The largest textural changes were observed in the range from 0 to 20 cm of the (P1-LIT) with the occurrence of clayey silt sediments and of (P5-LIT) with the occurrence of silt-clay-sandy sediments.

On the other hand, the granulometric distribution pattern between the layers of Lago do Bicho presented subtle textural variation between the intervals. In this lake, the silty sand texture prevailed, with an increase in the concentration of silt at depth in the (P2-LB) range of 40 to 60 cm. Notably, at point P3-LB, there was a significant increase in clay in the range of 20 to 40 cm, which was reflected in the texture that was classified as clayey sand (Fig. 3).

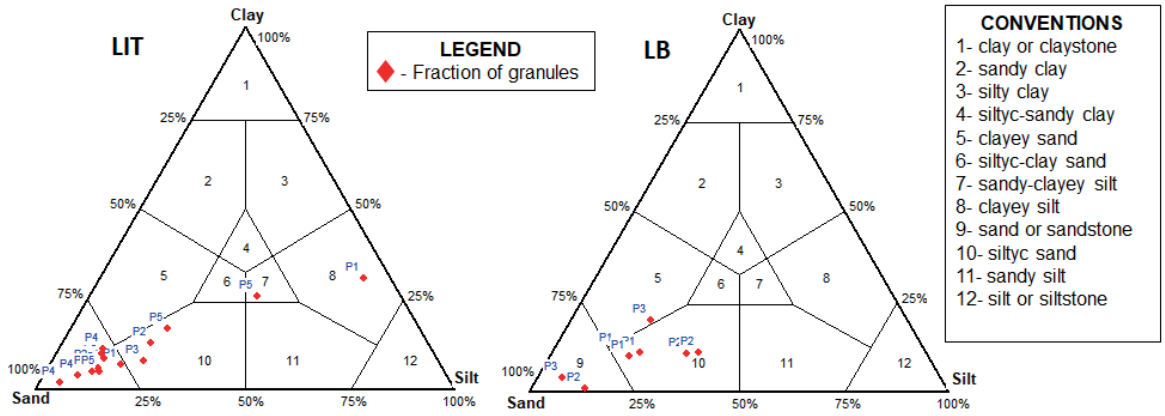

Fig. 3. Textural classification of sediments sampled in lakes. Each point and depth is indicated on Shepard's diagrams with blue letters and red symbol

The granulometric distribution in Lago do Italiano occurs in the order of 8% to 95% of sand in the entire sampled sequence, values of 3% to 61% of silt, and values of clay between 2% to 31%. In the (P1-LIT) range of 0 - 20 cm (center of the lake), there was a high concentration of silt in contrast to the absence of coarser granulometry in this surface layer. In Lago do Bicho, the sediments are dominated by a sand fraction with a content of 54% to 90%, silt with values from 6% to 35%, and clay with values from 4% to 20% (Fig. 4).

For what concerns the morphological analyses, it was evidenced that the lakes are constituted by angular and sub-angular grains. The angular grains varied between 0% and 50% and the sub-angular ones between 18% and 43%. The other grains, sub-rounded, rounded, and well rounded, occur in the order of 3% to 35%. The angular grains are present predominantly at the border of the Lago do Italiano at greater depth. In contrast, the sub-rounded grains prevail increasingly toward the center of the lake, in the more shallow layers with the interval of 0 to 20 cm (Fig. 5). Those grains are disposed of at greater depth and linked to a coarser material.

The largest part of the materials found in this group shows contrasting environmental conditions, such as redox status changes in some cases, with grains appearing crystalline, translucent, or more opaque, while others show yellowish chroma pigments and more brownish tones (Fig. 6).

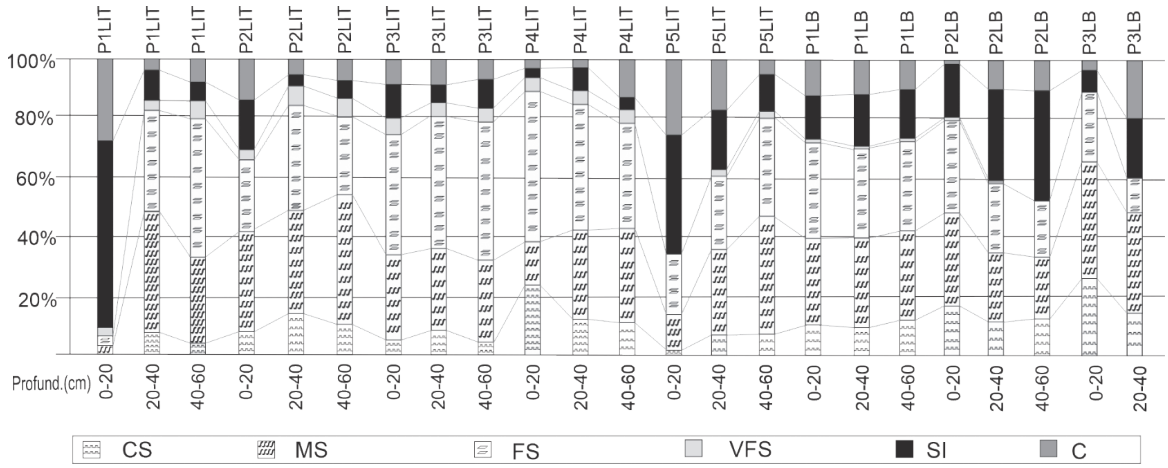

Fig. 4. Textural distribution of sediments along the profiles

Key: CS=coarse sand; MS=medium sand; FS=fine sand; VFS= very fine sand; SI=silt; C=clay.

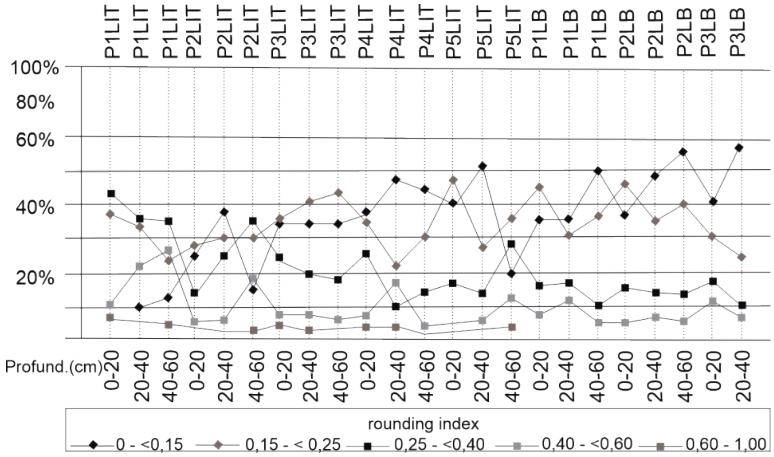

Fig. 5. Morphological sediment distribution at intervals of 0 to 60 cm

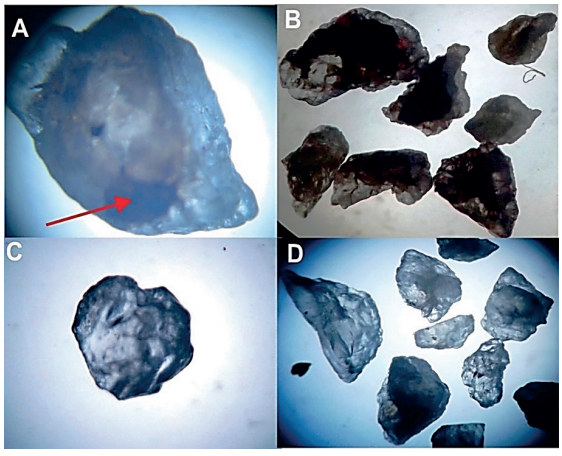

Fig. 6. Node presents zones of depletion and accumulation of Fe, corresponding to changes in the element's oxidation state. (B) Angular translucent grains with interior fabric with brownish pigment. (C) Sub-rounded grain presenting cavities. (D) Angular to sub-angular grains containing edges on the surface

The images generated by SEM showed different degrees of rounding and a variety of superficial features of mechanical origin such as abrasion marked surfaces, fractures, and edges. The sub-rounded grains show an expressive reworking, indicated by dissolution features on their surfaces (Fig. 7).

In order to confirm the visual observations, the minerals were detected through x-ray diffraction, which revealed in their spectra quartz, kaolinite, goethite, and muscovite, being similarly distributed between the intervals, with the exception of sediments at a depth of 0 to 20 cm of (P1), corresponding to the sample of the center of Lago do Italiano. Lower peak values for quartz were obtained in this interval, which may be justified by the concentration of organic matter in the samples of this profile.

Based on these data, the main chemical elements obtained from the total EDS chemical analyses can be distributed (Fig. 8). Such analyses evidenced and reinforced the discussion of the mineralogy found in the sediments where the occurrence of Si (69.1%) prevailed, and secondarily, Al_2O_3 contents (28.89%), reflecting the predominance of quartz and the significant participation of accessories such as kaolinite and muscovite. Despite low levels, the occurrence of FeO (0.87%) was also detected, associated with goethite, and TiO_2 (0.56%), which may be associated with Zircon (Fig. 7D), a mineral that was not identified at the x-ray diffraction peaks.

The chemical composition mapping also evidenced traces of SO_3 (0.58%) that has sulphur as its carrier and

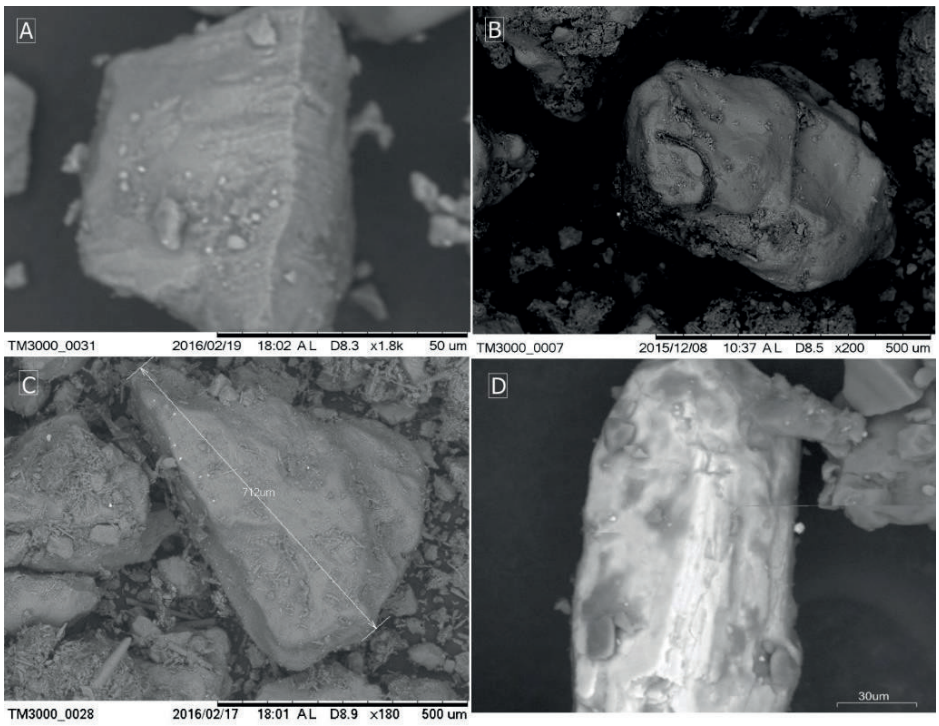

Fig. 7. Photomicrograph of grains obtained by SEM. (A) Detail of lenticular banding in quartz. (B) Grain with fractures and dissolution features on its surface. (C) Features of mechanical origin with abrasion edges in a quartz grain. (D) Zircon with rounded edges

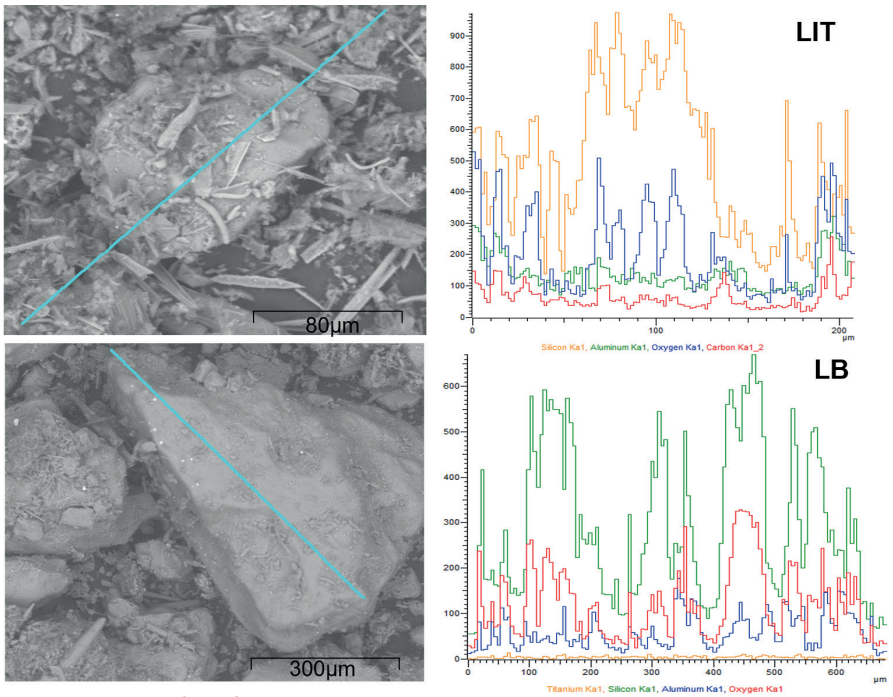

Fig. 8. Linear trace on the grain surface for microchemical mapping. The elements detected by EDS are shown in the graph on the side, where the occurrence of Si prevailed

is related to the in situ production of organic matter, as a consequence of the decomposition processes of macrophytes abundant in the lake. High levels of this chemical compound were found at the 0 - 20 cm interval, this being confirmed by the lower peak of quartz on XRD for this interval.

DISCUSSION

The presence of emerging macrophytes revealed the shallowness of the Lago do Italiano, Pinheiro and Jardim (2015), in analyses about the floristic colonization of lakes of similar shape, registered the occurrence of macrophytes in the horizontal zonation of the northern Amazon lakes: 45.8% of the species occur exclusively in the marginal areas; 12.5% in the intermediate area and 12.5% in the central area of the lakes.

Such results show that macrophytes' presence indicates eutrophication and is associated with abundant nutrient conditions (Ludikova 2021), suggesting a response of the ecosystem to the solar radiation intensity and temperature, these being: therefore, the main regulating factors of propagation. The rarefaction of emerging macrophyte species in the Lago do Bicho, on the other hand, is due to the morphometry of the basin and the constant water input, inhibiting productivity and vegetation settlement. In this regard, no vegetation was found in the central area of the lake. Thus, the plant cover variation surrounding the lakes must respond to the edaphic conditions, followed by the varied textural gradient, influencing the drainage dynamics and conferring vegetation heterogeneity.

Because these lakes possess a direct connection with the drainage network, they are fed seasonally (wet season) by the sediment input, mainly coming from canals of the first order, pointed out here as a possible source of sand for the system. The light textural variation observed in the shallow layers (Fig. 4) corresponds to the depositing pattern described by Thomas and Meybeck (1996). This occurs according to hydrodynamic energy differences, as the water's oscillating movement involves slow-moving currents and influences sediment transportation directions. The coarsest grain size values in the superficial layers of 0 - 20 cm entailed a directly proportional relationship to the silt concentration at this interval (Fig. 4). Generally, lake environments are places formed by sediments that present spatial grain size variation in a way that the coarsest material deposits occur near the borders. In contrast, fine texture materials occur in the central parts of lakes.

In this way, the angularity of the materials found in both lakes indicates that the sediments generally underwent short-distance transportation, evidencing that their source area is proximal. Barros et al. (2007) obtained similar data about sediment provenance in a coastal section stretch drained by the river Timbó in Pernambuco, northeastern Brazil. The predominance of angular and very angular grains (66%) in the sample analyses took these authors to acknowledge the sediment source area as being proximal, next to the river mouth.

The high degree of angularity of the Lago do Bicho sediments must be associated with the influence of the river Tacutu, which overflows during the periods of high precipitation and coalesces into the Lago do Bicho, delivering sediments to the lakes and plain, thus evidencing a strong seasonal control on the sediment transportation offer. Despite the minimal textural variation between the intervals, the granulometric distribution pattern between the layers showed a rise in silt concentration at a depth of (P2) of the Lago do Bicho. This is indicative of the material transportation from the highest point of the slope, that at reaching (P3), the contact with the water favors an energy reduction and, consequently, the precipitation of the finest materials near the river bed, while the coarsest fractions tend to concentrate at the borders of the lake. In this sense, the absence of coarser grain sizes in the shallow level of 0 - 20% in (P1, center of the Lago do Italiano) and high silt concentration at this interval may be observed (Figs. 3 and 4).

The nature of grains in the layers suggests an environment with low energy during the depositing process. The angular grains present sharp, well-preserved edges, pointing to source area proximity, causing little reworking during its transport, thus providing less opportunity for more rounding of the grains. Despite the sediments possessing quartz sand characteristics, they are not free of redoximorphic features that accumulate on the grains under the form of dark shaded nodes and stains, associated with saturation and desaturation of the water through groundwater level oscillation, resulting in a reduction of Fe compound precipitation (Fig. 6A).

Since we are dealing with lentic environments, the accumulation of organic matter is favored by the low hydrological energy and nutrition of organisms that influence the aspect of acidification of the medium, causing better preservation of the deposited organic matter (Fig. 6B). For example, grain size and carbon-nitrogen analyses of black water lakes, studied by Amorim et al. (2009), present organic matter as a consequence of in situ and marginal production processes, mainly by phytoplankton by the aquatic macrophytes. Furthermore, these studies provided evidence that these lakes possess more elevated levels of organic matter in the sediments for having more acidic waters that tend to better preserve it, beyond the fact that these lakes are characterized by low levels of suspended mineral matter that could dilute the organic content of the sediment.

The x-ray diffraction results (XRD) indicate the concentration of primary minerals such as quartz, followed by secondary phyllosilicates such as kaolinite, and secondary non-silicate minerals such as iron oxides, mainly goethite. These mineralogical; constituents encountered agree with the results obtained from SEM analysis. Furthermore, the presence of iron oxides usually favors the pigmenting action of the goethite, providing the sediment layers with the yellowish coloration, common to the inter-tropical regions, owing to the more pronounced weathering action in these areas.

Despite the mineralogy remaining quartzose, the occurrence of lithogenic metals as $ZrSiO_4$ is added (Fig. 7D). This occurrence is characteristic of granite rocks, made up essentially of quartz and feldspar, frequently registered among the coarse fractions of the detrital minerals in most of the sedimentary deposits, as they offer resistance to the natural wear caused by crustal processes (Machado et al. 2012). Furthermore, the adsorptive capacity of the fine-grained materials produces a directly proportional relationship with the occurrence of heavy metals and with the accumulation of organic matter in the superficial layers of the lake environments. The concentration of SO3 traces (0.58%) is related to the in situ production of organic matter, as a consequence of decomposition processes of macrophytes that are abundant in the lake, seeing that the organic matter is an important provider of sulphuric compounds for the sediments. The accumulation of organic matter in the Lago do Italiano is related to the proper sedimentation dynamics of the environment, where the greatest content changes occur after sedimentation. Due to the anaerobic conditions of these

environments, the production processes of organic matter are intensified to the detriment of the decomposition processes, thus permitting its accumulation (Drabkova 1983). The decomposition of plant residues, on the other hand, produces fine organic matter that appears under the form of pigments that are incorporated into the grains as dark or reddish-brown stains (Fig. 6A and B).

The most abundant element identified by EDX analysis, Si, presents the highest concentrations reflected in the mineralogy of the sand fractions. Thus, such results are in consonance with those found by Benedetti et al. (2011), corresponding to the same constituents encountered by the author in the rocks of the Boa Vista Formation. In this way, it can be inferred that the Boa Vista Formation is the probable provider of the analyzed lake sediments, arriving at these lakes through the seasonal oscillation of the groundwater level and the flooding pulses to which the plain of the river Tacutu is subjected. Being a tropical environment, with the incidence of high temperatures and precipitation, allied to the geological formation with predominantly sedimentary rock, there are rapid changes in the evolutionary patterns of the drainage network, triggering severe erosive processes that provoke filling in and siltation of these lakes (Santos et al. 2020).

The results, however, present extremely fragile lake environments due to their texture, predominantly sandy, indicating a low water retention capacity. With the fluctuation of the groundwater level, water retention is much less due to a strong seasonality, leaving the lake basin exposed and subjected to anthropic actions.

CONCLUSIONS

The lakes encountered in the studied area reflect the diversity of climatic and geomorphological conditions of the Amazon region. They present themselves in a variety of shapes and sizes, differing in the perennial or intermittent regimes, reflected mainly in the distribution of aquatic plant colonization and sediment transportation dynamics. While the Lago do Italiano is fed by sediments coming from first-order canals, a consequence of its direct connection with the drainage network, the Lago do Bicho receives a seasonal input of sediments coming from flood pulses of the river Tacutu.

Despite the differences in the transportation modalities that feed these lakes, the sediments concentrate on angular sandy grains, varying from medium to fine texture, with colors characteristic of redoximorphic processes. Such attributes were interpreted as resulting from hydrological behavior, marked by depositional successions of a low energy environment.

REFERENCES

Alves R. and Beserra Neta L. (2018). Geomorphological compartmentation and morphological classification of lacustrine environmentsin the savannahsof the northeastern region of Roraima. Journal Acta Geographic, Boa Vista: UFRR, 12(29), 1-18, DOI: 10.5654/acta.v12i29.3669. (in Portuguese with English summary)

Alves R. and Ribeiro S. (2018). Changes in the lake landscape result from the anthropogenic activity in Lago do Italiano in Bonfim – Roraima. Annals: XV National Congress of the Environment. [online]. Availlable at: http://www.meioambientepocos.com.br/Anais2018 [Acessed 27 Mar. 2021]. (in Portuguese with English summary)

Amaral M., Bittrich V., Faria A., Anderson L. and Aona L. (2008). Field guide for aquatic and marshland plants of the state of São Paulo. Ribeirão Preto: Holos, p. 452.

Amorim M., Moreira-Turcq P., Turcq B. and Cordeiro R. (2009). Origin and dynamics of superficial sediment deposits in varzea do large lake of Curuai, Pará, Brasil. Journal Acta Amazônica, 39(1), 165-172, DOI: 10.1590/S0044-59672009000100016.

Benedetti U., Vale Júnior J., Schaefer C., Melo V. and Uchôa S. (2011). Genesis, chemistry and mineralogy of soils derived from plio-pleistocene sediments and basic volcanic rocks in Roraima, northern Amazon. Brazilian Journal of Soil Science, 35(2), 299-312, (in Portuguese with English summary), DOI: 10.1590/S0100-06832011000200002.

Barbosa R. (1997). Distribution of rains in Roraima. In: R. Barbosa, E. Ferreira and E. Castellon, eds., Man, Environment and Ecology in the State of Roraima. Manaus, INPA, (in Portuguese with English summary), 325-335.

Barros L., Valença L., Manso V., Madruga Filho J. and Oliveira, J. (2007). Texture, composition and rounding of sediments of the internal continental platform, adjacent to the river mouth south of the Santa Cruz Canal and the river Timbó, north of the state of Pernambuco. Geological Studies, 17(1), (in Portuguese with English summary), 58-70.

Bootsma H.A. (2018). Oceans, Lakes, and Inland Seas: A Virtual Issue on the Large Lakes of the World. Limnology and Oceanography Bulletin, 27, 87-88, DOI: 10.1002/lob.10230.

Cardoso S., Quadra G., Resende N. and Roland F. (2019). The role of sediments in the carbon and pollutant cycles in aquatic ecosystems. Acta Limnologica Brasiliensia, 31(201), DOI: 10.1590/s2179-975x8918.

Costa M.L., Carmo M.S. and Behling H. (2005). Mineralogy and geochemistry of lake sediments with lateritic substrate in the Brazilian Amazon. Brazilian Journal of Geosciences, 35(2), (in Portuguese with English summary), 165-176.

CPRM . Geological Service of Brazil — Basic Geological Surveys Programme Brazil. (2009). Geological Map State of Roraima Scale 1:500.000, (in Portuguese with English summary), Manaus: CPRM.

Drabkova V.G. (1983). Bacterial decomposition of organic matter in lacustrine sediments. Hydrobiology, 99-102, DOI: 10.1007/BF00028435.

EMBRAPA. Brazilian Agricultural Research Corporation. (2018). Manual of soil analysis methods. 3rd ed., (in Portuguese with English summary), Rio de Janeiro.

Esteves F.A. (2011). Fundamentals of Limnology. 3rd ed. Rio de Janeiro: Interciência. (in Portuguese with English summary), 826.

Fassoni-Andrade A.C. and Paiva R.C.D. (2019). Mapping of the spatio-temporal sedimentary dynamics of river floodplains in the Amazon. Remote Sensing of the Environment, 221, 94-107, (in Portuguese with English summary), DOI: 10.1016/j.rse.2018.10.038

Folk R. and Ward W. (1957). Brazos River bar: A study in the significance of grainsize parameters. Journal of Sedimentary Research, 27(1), 3-26, DOI: 10.1306/74D70646-2B21-11D7-8648000102C1865D.

Franco E., Del'Arco J. and Rivetti M. (1975). Geomorphology. In: BRASIL. Projeto Radam Brasil. Survey of Natural Resources. Pages NA 20 Boa Vista and part of Pages NA 21 Tumucumaque, NB20 Roraima and NB21, Rio de Janeiro: IBGE.

Ludikova A.V. (2021). Long-Term Studies of Surface-Sediment Diatom Assemblages In Assessing the Ecological State of Lake Ladoga, The Largest European Lake. Geography, Environment, Sustainability, 14(1), 251-262, DOI: 10.24057/2071-9388-2020-174.

Guimarães J.T.F., Sahoo P.K., Souza-Filho P.W.M., Maurity C.W., Silva Júnior R.O., Costa F.R. and Dall'Agnol R. (2016). Late Quaternary environmental and climate changes registered in lacustrine sediments of the Serra Sul de Carajás, south-east Amazonia. Journal of Quaternary Science, 31(2), 61-74, DOI: 10.1002/jqs.2839.

Lorenzi H. (2017). Brazilian trees: manual for identification and cultivation of arboreal plants arbóreas native of Brasil. Plantarum Institute of Flora Studies Ltd.. 5th ed. São Paulo: Nova Odessa, 2, (in Portuguese with English summary), 384.

Machado D.A.M, Fernandes L.A., Góes A.M., Mesquita M.J. and Lima F.M. (2012). Origin of sediments from the Curitiba Basin by studies of heavy minerals. Brazilian Journal of Geosciences, 42(3), 563-572, (in Portuguese with English summary), DOI: 10.25249/0375-7536.2012423563572.

Maia P., Boaventura G. and Pires A. (2006). Spatial distribution of trace elements in the sediments of Lake Paranoá – DF, Brazil. Journal of Geochemistry Brasiliensis, 20(2), 158-174, DOI: 10.21715/gb.v20i2.242.

Melo V., Vale Júnior J. and Uchôa S. (2010). Use and maintenance of soil under Savannah. In: J. Vale Junior and C. Schaefer, eds., Soils under savannahs of Roraima: genesis, classification and environmental relations. Boa Vista: Gráfica Ioris, 219.

Meneses M., Costa M. and Costa J. (2007). The Lakes of the Lavrado of BoaVista — Roraima: physical-chemical physiographyof the water, mineralogy and chemistry of the sediments. Brazilian Journal of Geosciences, 37(3), 478-489, DOI:10.25249/0375-7536.2007373478489.

Moiseenko T., Sharov A., Voinov A. and Shalabodov A. (2012). Long-term changes in the large lake ecosystems under pollution: the case of the north-east European lakes. Geography, Environment, Sustainability, 5(1), 67-83, DOI: 10.24057/2071-9388-2012-5-1-67-83.

Murdoch A. and Macknight A. (1994). Handbook of Techniques for Aquatic Sediments Sampling. 2nd ed. Boca Roton, Florida: Lewis.

Pinheiro M. and Jardim M. (2015). Floristic composition and biological forms of aquatic macrophytes in lakes of the western Amazon, Roraima, Brazil. Journal Biota Amazônia, 5(3), 23-27, DOI: 10.18561/2179-5746.

Santos W., Silva P. and Moreira J. (2020). Hydro-sedimentological dynamics in fluvial lentic environment, Rio Branco, Acre: Initial investigation of silting process in fluvial canal. Journal GEOgrafias, 28(2), 135-156.

Santos Neto A., Tavares Junior S. and Souza V. (2013). Lacustrine Landscapes and Urban Expansion in the Municipality of Bonfim-RR. In: A. Filho and L. Beserra Neta, eds., Bonfim: A Geographical Vision. Boa Vista: Editora UFRR, (in Portuguese with English summary), 260

Shepard F. (1954). Nomenclature based on sand-silt-clay ratios. Journal of Sediment Research, 24(23), 151-158, DOI: 10.1306/D4269774-2B26-11D7-8648000102C1865D.

Simões Filho F., et al. (1997). Sedimentary registers of lakes and marshlands in the fields of Roraima: Paleo-environmental implications along the holocene In: R. Barbosa, E. Ferreira and E. Castellon, eds., Man, Environment and Ecology in the State of Roraima. Manaus, INPA, (in Portuguese with English summary), 295-302.

Suguio K. (1973). Introduction to Sedimentology. São Paulo: Edgard Blucher, 342.

Thomas R. and Meybeck M. (1996). The use of particulate material. In: D. Chapman, ed., Water Quality Assessments: a guide to the use of biota, sediments and water in environmental Monitoring, 2nd ed., UNESCO/WHO/UNEP.

Vonk J.E., Dickens A.F., Giosan L., Hussain Z.A., Kim B., Zipper S.C., Holmes R.M., Montlucon D.B., Galy V. and Eglinton T.I. (2016). Arctic Deltaic Lake Sediments As Recorders of Fluvial Organic Matter Deposition. Frontiers in Earth Science, 4(77), 1-24, DOI: 10.3389/feart.2016.00077.

Xu Y., Wu Y., Han J. and Li P. (2017). The current status of heavy metal in lake sediments from China: Pollution and ecological risk assessment. Ecology and Evolution, 7(14), 5454-5466, DOI: 10.1002/ece3.3124.

Zdorovennova G., Palshin N., Zdorovennov R., Golosov S., Efremova T., Gavrilenko G. and Terzhevik A. (2016). The Oxygen Regime of a Shallow Lake. Geography, Environment, Sustainability, 9(2), 47-57, DOI: 10.15356/2071-9388_02v09_2016_04.