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Artigo de Pesquisa

Geomorphological aspects of the Jirau 01 fossiliferous natural tank, municipality of Itapipoca, Ceará state, Brazil

Aspectos geomorfológicos do tanque natural fossilífero Jirau 01, município de Itapipoca, estado do Ceará, Brasil

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Abstract: The natural tanks (*stricto sensu*) are important geomorphological features that occur in the municipality of Itapipoca (CE), which occasionally accommodate Quaternary sediments with relevant fossil content. The "Tanque Jirau 01", located at the Jirau Paleontological Site, stands out among the various depressions that occur in this municipality of Ceará, both in terms of geomorphology and paleontology. The Jirau fossiliferous tank (TF01) is a steep natural tank, which was formed in the crystalline basement, presenting a concave-type bottom morphology. The depression follows the WNW-ESE orientation and is partially filled by sand-clayey sedimentary deposits, with fossiliferous content from the Pleistocene megafauna. Regarding dimensional aspects, the TF01 has an extension of more than 50 meters in length, with a maximum width of 5,30 meters and depths of up to 5 meters. The conformity of the geomorphological aspects, in addition to attributing to the TF01 an extraordinary scenic beauty, also made it possible to offer, in the past, an area of stock and availability of water for the fauna and, later, for the local population in periods of drought. Inside the tank, it is possible to verify the registration of minor structures on the lateral walls, features similar to honeycombs and/or alveoli with centimeter sizes, and evidence of weathering processes of soil-rock contact linked to chemical corrosion. Although there are paleontological studies in academia on the material found in the depressions of Itapipoca, there is still few materials linked to the conditions responsible for the possible origin and development of these natural tanks in the region. This study presents an initial analysis based on the morphological characterization and tectono-structural control of the Jirau 01 (TF01) natural tank, an area of important scientific reference in the municipality of Itapipoca (CE).

Keywords: Geomorphology; Natural tank; Megafauna; Quaternary geology; Northeastern Brazil.

Resumo: Os tanques naturais (*stricto sensu*) constituem importantes feições geomorfológicas que ocorrem no município de Itapipoca (CE), os quais acomodam, ocasionalmente, sedimentos quaternários com relevante conteúdo fossilífero. O "Tanque Jirau 01", situado no Sítio Paleontológico Jirau, tem destaque entre as diversas depressões que ocorrem no município cearense, tanto no aspecto geomorfológico quanto paleontológico. O tanque fossilífero Jirau (TF01) é um tanque natural escarpado, que foi formado no embasamento cristalino, apresentando morfologia de fundo do tipo côncavo. A depressão segue a orientação WNW-ESE e encontra-se, parcialmente, preenchida por depósitos sedimentares areno-argilosos, com conteúdo fossilífero proveniente da megafauna cenozoica. Em relação aos aspectos dimensionais, o TF01 possui uma extensão com mais de 50 metros de comprimento, dispondo de uma largura máxima de 5,30 metros e profundidades de até 5 metros. A conformidade dos aspectos geomorfológicos, além de atribuir ao TF01 uma extraordinária beleza cênica, também permitiu oferecer no passado uma área de estoque e disponibilidade de água para a fauna e, posteriormente, a população local em períodos de estiagem. No interior do tanque é possível verificar o registro de estruturas menores nas laterais, feições semelhantes a favos de mel e/ou alvéolos com tamanhos centimétricos, e indícios de processos intempéricos de contato solo-rocha vinculados à corrosão química. Embora exista no meio acadêmico estudos paleontológicos sobre o material encontrado nas depressões de Itapipoca, ainda há pouco material vinculado aos condicionantes responsáveis pela possível origem e desenvolvimento destes tanques naturais na região. O presente estudo traz uma análise inicial a partir da caracterização morfológica e do controle tectono-estrutural do tanque natural Jirau 01 (TF01), área de importante referência científica no município de Itapipoca (CE).

Palavras-chave: Geomorfologia; Tanque natural; Megafauna; Geologia do Quaternário; Nordeste do Brasil.

1. Introduction

"Natural tanks" (*stricto sensu*), alongside their "tank deposits" (sedimentary deposits), constitute important relief features on the Brazilian Northeast, being eventually converted into paleontological and archeological sites of reference (BERGQVIST et al., 1997; XIMENES, 2003, 2006a, 2006b, 2009; XIMENES; SANTOS, 2011; BARRETO et al., 2004; SILVA, 2007; SILVA; CORRÊA, 2009; SILVA; CORRÊA; AMORIM, 2017; SANTOS JÚNIOR, 2005, 2013; SANTOS JÚNIOR; PORPINO; SANDERSON, 2008; SANTOS JÚNIOR et al., 2015; ARAÚJO-JÚNIOR; PORPINO; BERGQVIST, 2015; WALDHERR; ARAÚJO-JÚNIOR; RODRIGUES, 2017a; WALDHERR et al., 2019). "Natural tanks" (*stricto sensu*) correspond to depressions produced over the crystalline basement, being found in terrains formed by igneous or metamorphic rocks and, occasionally, in sedimentary rocks (PAULA-COUTO, 1980; OLIVEIRA; HACKSPACHER, 1989; MABESOONE; OLIVEIRA; DAMASCENO, 1990; SANTOS et al., 2002; XIMENES, 2003, 2009; ARAÚJO-JÚNIOR; PORPINO, 2011; LIMA; SILVA, 2016; WALDHERR; ARAÚJO-JÚNIOR; RODRIGUES, 2017a; WALDHERR et al., 2019; FARIA; CARVALHO; ARAÚJO-JÚNIOR, 2020).

Natural tanks in the Brazilian Northeast, once exposed to the surface, have played a role as preferential axes for the coalescence of sediments and influxes from the surface runoff throughout geological time. It is important to remark that, among the material carried into the depressions, bone fragment clusters can be found, converting natural depressions in authentical thanathocoenosis, albeit the restricted scale (WALDHERR et al., 2019). In the municipality of Itapipoca, on the northern area of Ceará state, natural tanks are recurrent forms around the granitic massif of Uruburetama (XIMENES, 2003), comprised of narrow depressions filled by sedimentary deposits where, occasionally, fossil remains from the Quaternary megafauna are preserved and found.

According to surveys conducted in the municipality of Itapipoca by Ximenes (2003, 2006a, 2006b, 2009), the natural geological and geomorphological characteristics favored the formation of one of the largest concentrations of such kind of depression associated with paleontological deposits, and which are distributed throughout an area of more than 800 km² over the crystalline basement. Yet, according to the author, the paleoclimatic conditions were favorable for the development of a diversified fauna of vertebrates, with more than 30 already identified taxons of mammals, reptiles, amphibia and aves being found only in the municipality of Itapipoca (XIMENES, 2009; ARAÚJO-JÚNIOR; MOURA, 2014; ARAÚJO-JÚNIOR et al., 2013). Due to the concentration of fossiliferous deposits in the natural tanks, alongside the abundant paleontological material collected and the expressive representativity of different species of paleomammals, the area located in between the drainage of the Cruxati and Mundaú rivers, in the municipality of Itapipoca, has been referred to as the "Valley of the Prehistorical Megafauna" (XIMENES, 2003, 2006b, 2009).

The association between the geomorphological conformation of natural tanks and the fossiliferous deposits constitutes a characteristic which is, until the present moment, exclusive (*sui generis*) to the Brazilian Northeast.

Although, features similar to natural tanks have been recorded, both in different regions of South America and continents, there is no documentation or records on fillings linked to fossiliferous deposits of prehistorical megafauna, especially, those from the Quaternary period. In the municipality of Itapipoca it is possible to select five important paleontological sites where the rescue of fossils happened through the excavation of deposits in tanks, which are: Jirau, Coelho, Lajinhas, João Cativo e Pedra D'água (Figure 1) (XIMENES, 2003, 2006a, 2006b, 2009; XIMENES; SANTOS, 2011).

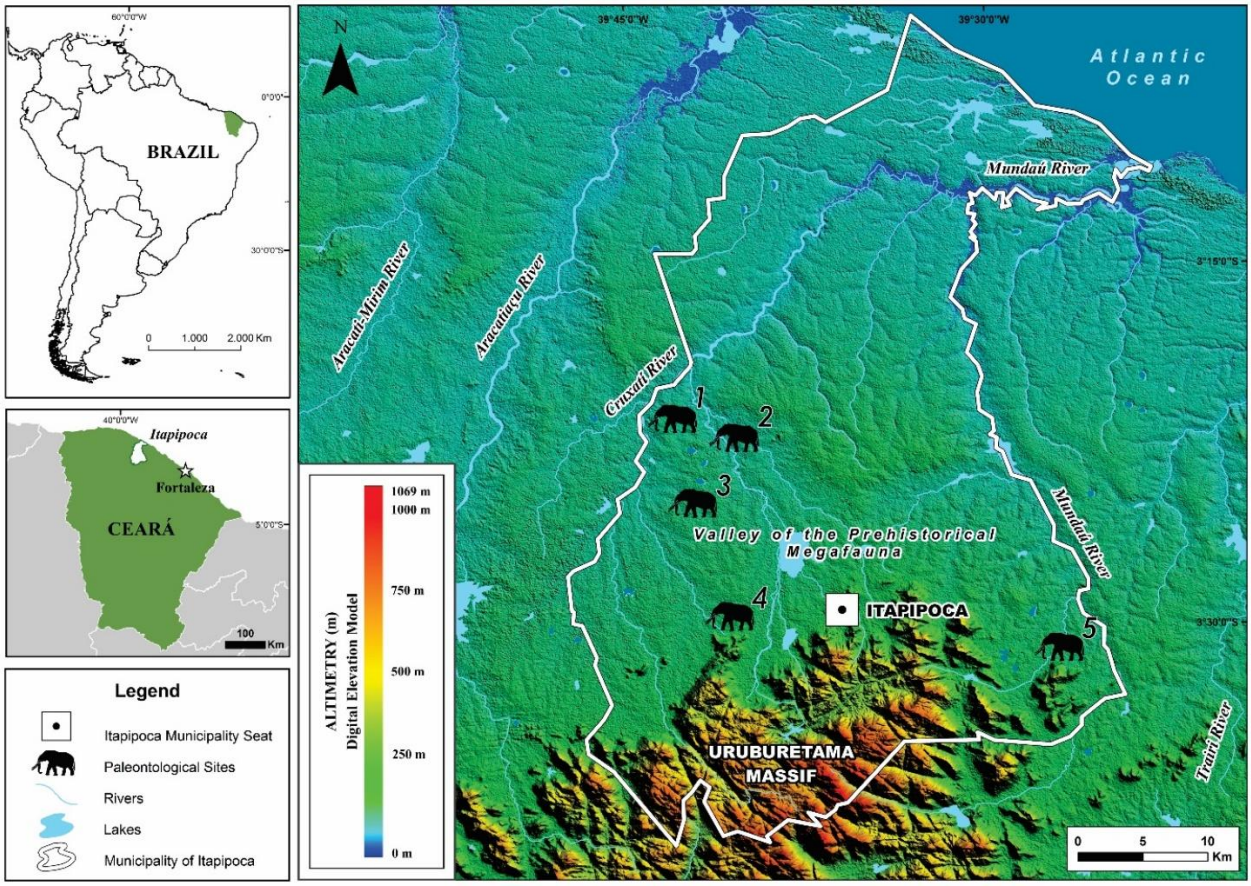

Figure 1. Location of the study area with the geographical distribution on the main Paleontological Sites with the occurrence of fossiliferous natural tanks in the municipality of Itapipoca, Ceará state, Brazil. These are: (1) Jirau Paleontological Site; (2) Coelho Paleontological Site; (3) Lajinhas Paleontological Site; (4) João Cativo Paleontological Site; e (5) Pedra D'água Paleontological Site. The altimetry datas used in shaded relief on Figure 1 was obtained through PALSAR radar orbital sensor (ALOS satellite).

The Jirau Paleontological Site, a reference area for the present study, was discovered in 1993 through a paleontological prospection, funded by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) scientific initiation program of the Universidade Federal do Ceará (XIMENES, 2003). The initial work was restricted to the mapping of natural tanks, photographic documentation and collection of fossils samples. According to Ximenes (2003), in the inside of the tanks, there were *cacimbas* (water-holes) over the deposits, excavated by the local inhabitants to collect water, resulting in the exposal of fossiliferous levels and, consequently, the loss of several bone fragments. At the time, an agreement was reached with the landowners, with the institutional support of the Itapipoca City Hall. Afterwards, a series of surveys, especially of paleontological concern, were conducted at the Jirau tanks in the years of 2001, 2003, 2009, 2012 and 2015, resulting in new excavations and important contributions to the studies, especially the taphonomic ones, from the fossils collected in tank deposits (ARAÚJO-JÚNIOR, 2012, 2015, 2016; ARAÚJO-JÚNIOR; PORPINO; BERGQVIST, 2011a; ARAÚJO-JÚNIOR et al., 2011b, 2013). As the sedimentary deposit was removed from the inside of the natural tank, the bottom morphology and the set of minor structures on the lateral walls were gradually exposed from the soil-rock contact, then present. According to Araújo-Júnior (2015) it was possible to rescue, through the excavations

performed over the tank deposits at the Jirau Paleontological Site, a total of 1.405 fossils until this moment. The fossiliferous material collected was sent, afterwards, to the Museu de Pré-história de Itapipoca (MUPHI).

At the Jirau Paleontological Site natural tanks are distributed over the granite terrain and correspond to a total number of seven depressions, although it was possible to perform the collection of fossiliferous material from the tank deposits in only three of them. It is important to remark that, so far, no procedures connected to dating material collected inside the natural tanks were performed. Currently, tanks are used as water reservoirs during drought periods. In this present study, the natural tank with the largest dimension was selected, being named by previous studies as "Jirau 01 Tank" (XIMENES, 2003, 2009; ARAÚJO-JÚNIOR, 2012, 2015).

2. Study Area

About 21 kilometers northwest of the Itapipoca city hall, fossiliferous tanks occur and constitute the Jirau Paleontological Site, forming a set of depressions developed over the granite outcrops locally known as *lajedos* (Figure 2). This granitic outcrop, which contains the depression named "Jirau 01 Fossiliferous Tank" (TF01), has a total area of 5.260m² and is leveled at height of 60 meters. Its UTM coordinates are: (24M Zone) 421627.00 m E / 9628979.00 m S. The main entrance points to the Jirau Paleontological Site are the vicinities of Barra do Macaco and Lagoa do Juá.

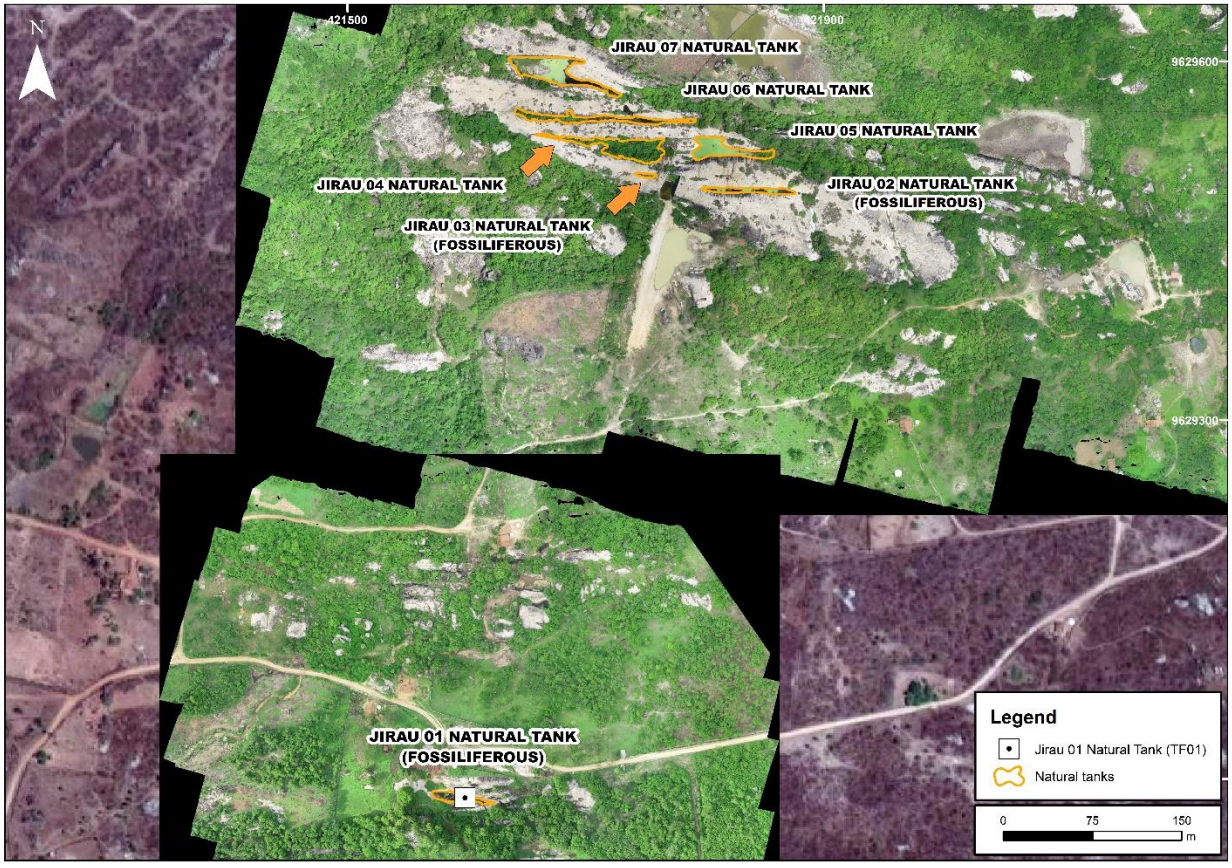

Figure 2. The geographical distribution of the seven natural tanks studied at the Jirau Paleontological Site, municipality of Itapipoca (CE), Brazil.

The geological basement of the study area is completely located at the Borborema Structural Province, specifically at the Central Ceará Domain (ALMEIDA et al., 1981; ARTHAUD et al., 2008; BRAGA; GOMES, 2014, 2018). Rodrigues et al. (2010) define the Province as a vast brasiliano region constituted by metamorphic and igneous lithologies, formed by a branched system of neoproterozoic orogens, separated by proterozoic age terrains which, eventually, show archean nuclei (ALMEIDA et al., 1981; BRITO NEVES; SANTOS; VAN SCHMUS, 2000). According to the geological mapping conducted by the CPRM (BRAGA; GOMES, 2014, 2018), on a 1:100.000 scale, the Jirau Paleontological Site, where natural tanks occur, is located over the Penedos Leucogranite lithologic unit (Figure 3), pertaining to the late- to post-orogenic magmatic suite (Cambrian to Ordovician). Yet, according to the

geological mapping, the surroundings of the area of the natural tank are constituted, in decreasing chronological order, by alluvial deposits, colluvial-eluvial deposits, both of Cenozoic age, and by the Santa Quitéria Granitoid, pertaining to the Tamboril-Santa Quitéria Complex (Neoproterozoic).

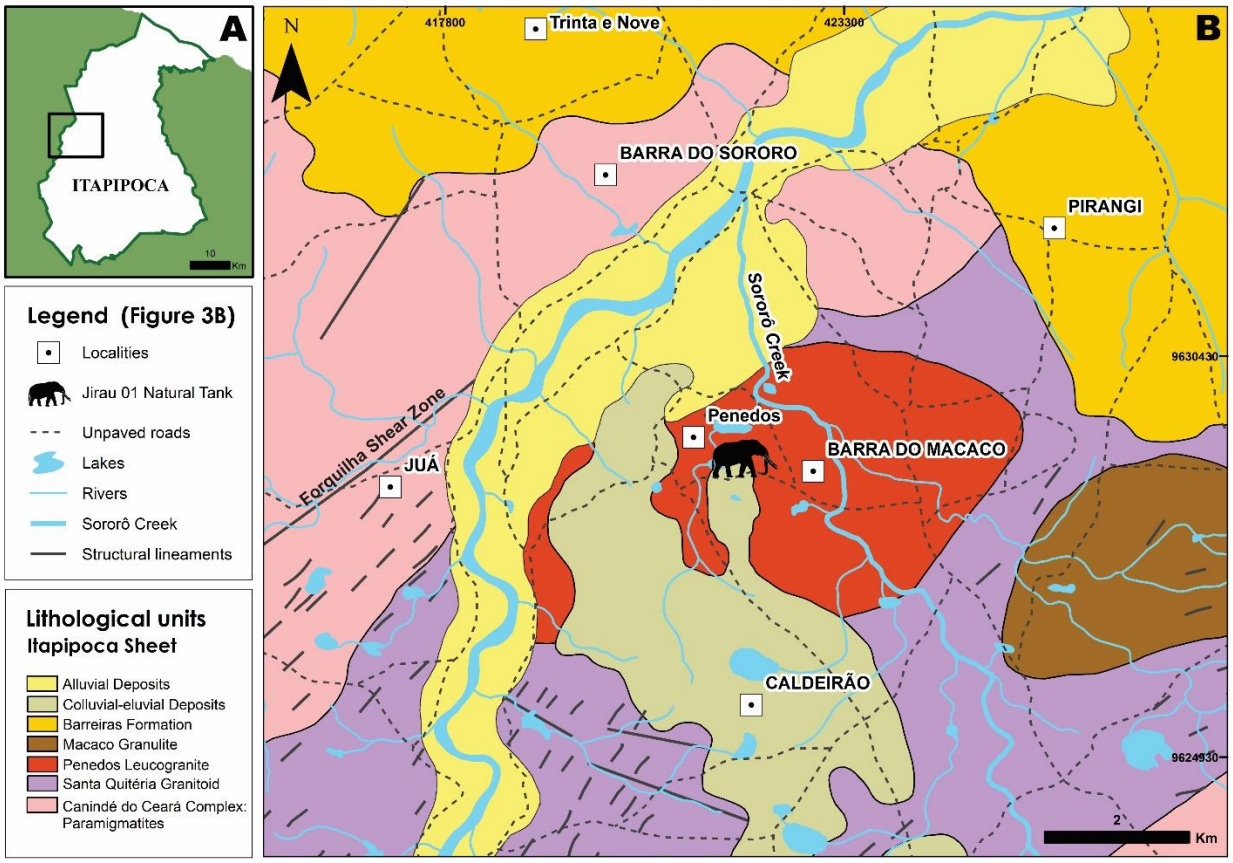

Figure 3. Geological map of the Itapipoca Sheet (SA.24-Y-D-II) and the location of the Jirau 01 natural tank. A - The geological mapping selection at the municipality of Itapipoca, in the Ceará state; B - The location of the Jirau 01 natural tank. The tank is entirely located over the Penedos Leucogranite lithologic unit, pertaining to the late- to post-orogenic magmatic suite, and close to contact with the colluvial-alluvial deposits. Source: Modified from Braga and Gomes (2014).

The Penedos Leucogranite lithologic unit corresponds to the off-white to rosy granitoid outcrops which are found in the vicinities of Penedos and Barra do Macaco. According to Braga and Gomes (2018), the unit is constituted, predominantly, by syenogranites, isotropic, coarse granulation, with a low degree of alteration and rarely fractured. Macroscopically, they are formed by feldspars, quartz, having biotite, amphibole, as well as garnets which vary from 0,4 to 1,0 cm. Yet, according to the authors, the unit outcrops as granite platforms (*lajedos*) or low domes, most times of large extension, surrounded by non-consolidated coverings (BRAGA; GOMES, 2018). In relation to the structural and tectonic aspect, the Penedos Leucogranite lithological unit which comprises the crystalline basement of the study area presents a structural arrangement marked by a main NE-SW trend, which conditions the format of the late- to post-orogenic magmatic suite (BRAGA; GOMES, 2018).

According to the geomorphological classification proposal of the septentrional Brazilian Northeast, elaborated by Costa et al. (2020), the Jirau Paleontological Site finds itself inserted in the "Superfície Sertaneja 1" (SS1), previously integrated to the macro-compartment named traditionally as "Depressão Sertaneja" (MAIA; BEZERRA, 2014). Yet, according to the authors, Superfície Sertaneja 1 corresponds to the lower terrains, constituting itself in areas where the planation processes are more evident. In relation to the altimetric variation, the compartment is located in between the 50 to 250 meters quotas, with plain or slightly wavy topographies (COSTA et al., 2020). It is important to remark that the area as a whole is drained by the Sororô Creek and affluents, with its hydrographic regime characterized by presenting an intermittent or temporary regime (SOUSA, 2009).

In the study area, the Superfície Sertaneja 1, drained by the Sororô Creek (affluent of the Cruxati River), corresponds to a morphology of ample regional expression which varies topographically from plain to slightly rugged, constituting a surface with altitudes ranging from 40 to 80 meters. In synthesis, the landscape is constituted by an extensive razed surface, covered predominantly by colluvial-alluvial deposits, being occasionally marked by granite outcrops (*lajedos*), similar to a leveled mosaic where altimetric quotas reach the 60 meters on average. However, the continuity of the surface is interrupted, in its south portion, by the presence of the granitic monolith of Uruburetama, where the source of the Sororô Creek is located. The orographic barrier reaches the altimetric quota of 1.081 meters in its peak point, besides constituting an important retainer of humid air masses coming from the Atlantic Ocean. Thus, among the recurrent features of the granitic terrain, typical of the sertanejo hinterland setting which constitutes the study area, it is possible to observe the occurrence of ''Major forms'' or ''Macroforms'', for instance, inselbergs, bornhardts and cupuliform domes, being represented, mainly, at the Uruburetama Massif set, and the ''Minor forms'' or 'Microforms'' which correspond to matacões, tors, tafoni, alveoli and natural tanks (*tanques naturais*). It is important to note that previous studies about the Uruburetama Massif have verified the preponderant role of the structural and lithological control on the development of the set and disposition of granitic terrain forms associated to ''Major and Minor forms'' (BRAGA; GOMES, 2014, 2018; LIMA, 2018; LIMA et al., 2019), including the granite outcrops (*lajedos*) and natural tanks orientation which constitute the paleontological sites in the municipality of Itapipoca.

3. Methodological Procedures

Two fieldworks, in July 2019 and January 2020, were conducted in the objective of ranging the pre-established points alongside the main natural tanks at the Jirau Paleontological Site, in the municipality of Itapipoca, Ceará state. The pre-estabilished points were selected based on the preliminary identification of natural tanks through high-resolution images obtained using RPA (Remotely Piloted Aircraft) and through the set of bibliographic references linked to the study area (articles, papers, thesis, etc.). The Jirau 01 natural tank, located at a granite outcrop (*lajedo*), was selected as a reference area for the present study as it is the largest depression at the Jirau Paleontological Site.

The high-resolution images used were obtained through a Class 3 RPA, Phantom 4 Pro model, equipped with a 20 megapixel camera of coupled resolution. The aerial surveys were conducted from overflights 100 meters above ground, providing a Ground Sample Distance (pixel representation of terrain image) of 2.73 cm. The overflight application used was Pix4D Capture, installed in a mobile device with iOS operational system (iPhone 6). Image processing was performed in the aerophotogrammetry software *Agsoft Photoscan*. As generated products, georeferenced ortophotomosaics of 2.7 cm pixels were produced, and digital models of elevation (MDE) with high spatial resolution.

In the high spatial resolution image obtained through RPA, an extraction of structural lineaments observed on the granite outcrops (*lajedos*) where natural tanks occur was performed. The technique used for the lineament extraction is described in Goldtien and Marshak (1988). Authors defined that the lineament extraction scale must be fixed. In the present study, high spatial resolution images obtained through RPA were used. Two types of products were used: colorful optical image (true color) and shaded relief maps manufactured from the obtained MDE. Four shaded relief maps were used, with lighteners positioned at N360º, N45°E, N90ºE and N45°W, all with a 45º angle tilt. The lineaments extracted on shaded relief maps were compiled and treated together, with duplicated lineaments being deleted. The lineament properties (azimuth, length) were obtained automatically on the ArcGIS 10.3.1 software and data treated with the Polar Plots extension (JENNESS, 2014). Rosette diagrams were then generated, using the sum of lengths in azimuthal intervals of 10º and frequency of lineament orientations.

Points were registered and later integrated into the digital environment with the assistance of the GPS device Garmin 64s. During the fieldwork survey, a diagnosis of the different aspects and the minor structures inside of the Jirau 01 natural tank was performed, besides the possible geoenvironmental constraints responsible for the formation and development of the natural depression over the crystalline basement.

The morphometric classification, as the genetic type, is based on characteristics defined by Mayor Rodríguez (2011) for features analogous or similar to natural tanks, which are: the length, width, depth and presence or absence of outlet (exutório) in the cavity area. In its turn, bottom type morphology is based on the Twidale and Vidal-Romaní (2005) and Waldherr, Araújo-Júnior and Rodrigues (2017a) proposal for the Brazilian Northeast tanks.

Morphometric analysis was performed from the cartographic bases used in the present study, elaborated from the PALSAR radar orbital sensor (ALOS satellite), which presents spatial resolution of 12.5 meters. From the DEM, level curves were generated, with a 10 - meter spacing, using the Global Mapper 15 software. The level curves were elaborated with the purpose of checking different altimetric levels, relief amplitude, distribution of geomorphic formations and drainage axis orientation in the municipality of Itapipoca (Ceará). Digitalization, georeferencing and data integration were performed on the ArcGIS 10.3.1 and Global Mapper 15 software.

4. Structural control and acting processes

In morphological terms, granite is a rock that originates a wide variety of relief forms and presents itself on landscape both as a resistant and a friable rock (DERRUAU, 1983). Such variations are controlled by the presence of massive domains and fractured domains vulnerable to the chemical weathering in subedaphical environments (AMARAL, 1973, 1974; PEDRAZA, 1989, 1994, 1996; TWIDALE, 1982, 1989, 1998, 2002; TWIDALE; VIDAL-ROMANÍ, 2005; VIDAL-ROMANÍ, 1989; VIDAL-ROMANÍ; TWIDALE, 1998; DEMANGEOT, 2000; MIGÓN, 2006, 2010; MAYOR RODRIGUEZ, 2011; MAIA; NASCIMENTO, 2018; MAIA et al., 2018; LIMA, 2018; LIMA et al., 2019) and mainly to the paleoclimate. The density of the opened fractures/joints systems is a preponderant factor throughout the weathering process, even prevailing over intrinsic properties such as texture and mineralogical composition of granite (TWIDALE, 1982, 1986a, 1986b, 1989, 1998).

According to Vidal-Romaní and Twidale (1998), the opened fractures are the main entry points for the meteoric water to penetrate along the crystalline basement. Twidale (1986a) indicates that the granite presents low porosity with representative values under 1%, normally corresponding to the 0.1% range, thus having low permeability or deficiency in the capacity of transmitting water through a rock body. However, a few granite masses are highly permeable due to the number and density of opened fractures/joints. Alongside fractures and permanently in contact with the water (humidified regolith), the rocky substrate is rapidly altered. The weathering front migrates from the fracture layers, for instance, to the so-defined slate boulders, converting angular blocks into rounded nuclei. The processes of the solution, hydration, hydrolysis and oxidation are responsible for the rock attrition and disintegration, even though bacterial action might in a certain way facilitate the water penetration on a granulometric scale (TWIDALE; VIDAL-ROMANÍ, 2005).

According to Twidale (1986a), the weathering front is irregular, once there is a tendency for any position of the rocky surface to be attacked and altered, preferentially on areas considered susceptible to chemical weathering, for instance, over the fractures/joints systems (intersection) and compositional layering of the intrusive body. The author also affirms that some of the weathering fronts, when exposed, are notably smooth. However, in other cases, differential weathering acts directly over the feldspar and mica minerals through chemical corrosion, sparing the quartz crystals and reshaping the orthoclase and microcline phenocrystals into microrelief. The effect of the preferential chemical corrosion over the different minerals which constitute granite results in a pitted surface. Such a corrosive effect can be observed over the granite outcrops (*lajedos*) and inside the depressions that form the natural tank.

Another mechanism that can be observed on the lateral walls of the tanks, once exposed, is the so-named disaggregation in plates (flaking) and granular disaggregation. According to Mayor Rodríguez (2011), plates can have a thickness between 1 to 10 mm, even though They can be thicker, ranging from 1 to 15 cm, and for those the term scaling has been used. Thus, flaking might occur in a simple or multiple way. Granular disaggregation of less advanced stages, in turn, starts in the disaggregation from the grain and, later, the mechanism spreads centrifugally from the removed unit.

It is important to remark that another process has been considered in specialized literature for the origin of forms similar to the Brazilian natural tanks, being named as migration or concentration of charges. The process application, in subedaphical environments, became a basis for the model based on charge application, inducted by the migration and concentration of charges in specific areas of the crystalline basement. The tension applied in certain points, for instance, between the set of fractures/joints (sheet structure), would result in internal elastic deformations which, throughout time, might become permanent (VIDAL-ROMANÍ, 1984, 1985, 1989, 1990, 2008; VIDAL-ROMANÍ et al., 2014a, 2014b, 2018; MAYOR RODRÍGUEZ, 2011; WALDHERR; ARAÚJO-JÚNIOR; RODRIGUES, 2017a; WALDHERR; VIDAL-ROMANÍ; RODRIGUES, 2018a; WALDHERR et al., 2018b, 2019). These specific points configure areas that are susceptible and preferential to the weathering attack, both in subsurface, as demonstrated from geophysical evidences (ROQUÉ; ZARROCA; LINARES, 2013), as well as in

subaerial conditions (MAYOR RODRÍGUEZ, 2010; VIDAL-ROMANÍ; UÑA ALVAREZ; VAQUEIRO RODRÍGUEZ, 2014a; VIDAL-ROMANÍ; VAQUEIRO RODRÍGUEZ; SANJURJO SÁNCHEZ, 2014b; VIDAL-ROMANÍ; VAQUEIRO RODRÍGUEZ; VÁZQUEZ, 2018).

5. Analysis of structural lineaments

From the shaded relief maps, 283 structural lineaments were compiled. The rosette diagram, result of the sum of lineament orientation frequency vs. orientation (Figure 4), demonstrated that the study area and surroundings highlight two main lineament orientations, the WNW-ESSE and NW-SE directions, indicating a small difference from the lineaments interpreted in the optical image (true color). The WNW-ESE Direction significantly reflects most part of the observed lineaments, in those highlighted on the optical image (true color) as well as on the shaded relief maps. Directions also indicates the main orientation analyzed in the delimited granite outcrops (*lajedos*).

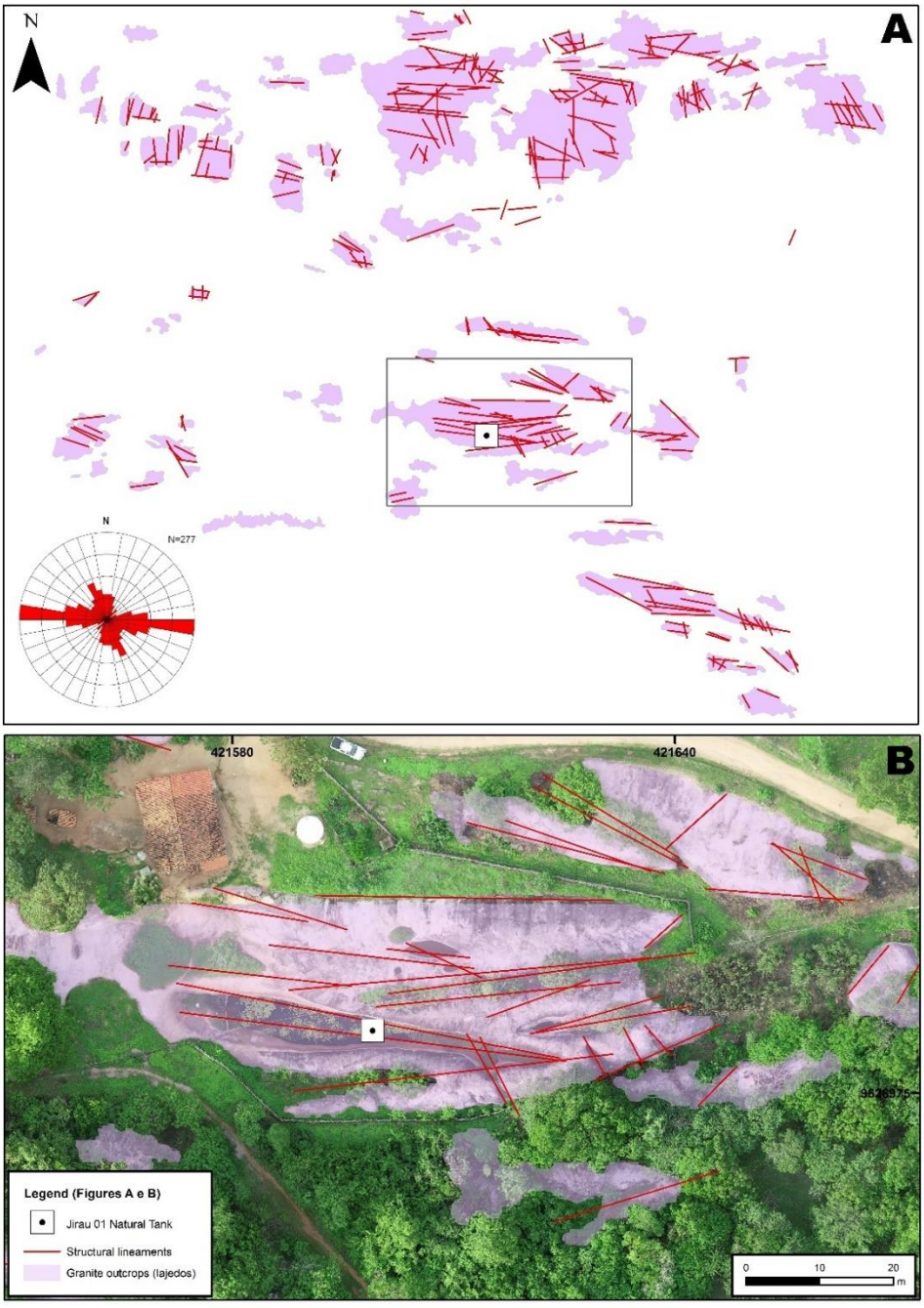

Figure 4. Structural lineaments and Jirau 01 natural tank location map. A - Lineament distribution over the leucogranite outcrops obtained on the optical image in natural color; B - Jirau 01 natural tank, in detail, over the granite outcrop (*lajedo*) with the main lineaments.

6. The natural tank and the minor structures

The Jirau 01 natural tank developed over the ruptile/ductile structures on the granite outcrop (*lajedo*). The disposition of lineaments set, as well as the degree of deepening linked to the physical-chemical weathering, reflect over the geomorphological feature of the crystalline basement (Figure 4B). According to the classification for the different forms of natural tanks in the Brazilian Northeast, elaborated by Waldherr, Araújo-Júnior and Rodrigues (2017a), "Jirau 01" can be understood as a rugged natural tank of large dimensions with bottom morphology of the concave type.

In general lines, the Jirau 01 natural tank (TF01) presents a continuous development plan which can be analyzed, separately, through two sections. The main lineament of the tank presents a WNW-ESE (N80W) direction. The depression is contained by two granitic abutments which extend almost continuously until the outlet or opening. The longitudinal profile of the natural tank presents a total extension of 53 meters in length (Figures 5 and 6). The maximum width between the abutments has 5,30 meters and the morphology varies according to the analyzed section, being symmetrical in the first and asymmetrical in the second section. In turn, the bottom of the depression, in spite of keeping a concave pattern, presents different levels of deepening, reaching 5 meters of depth. The segmentation between the sections of the natural tank sets itself from a fracture obliquely positioned Against the longitudinal axis of the depression. The oblique fracture is in a N30W direction, having an extension of 3,50 meters of length (Figure 7).

Figure 5. Image of the Jirau 01 natural tank obtained from the drone overflight at the Jirau Paleontological Site.

Figure 6. Jirau 01 natural tank over the granite outcrop (*lajedo*), integrated to the Jirau Paleontological Site. The depression is used as a water reservoir during dry periods. Facing the East direction.

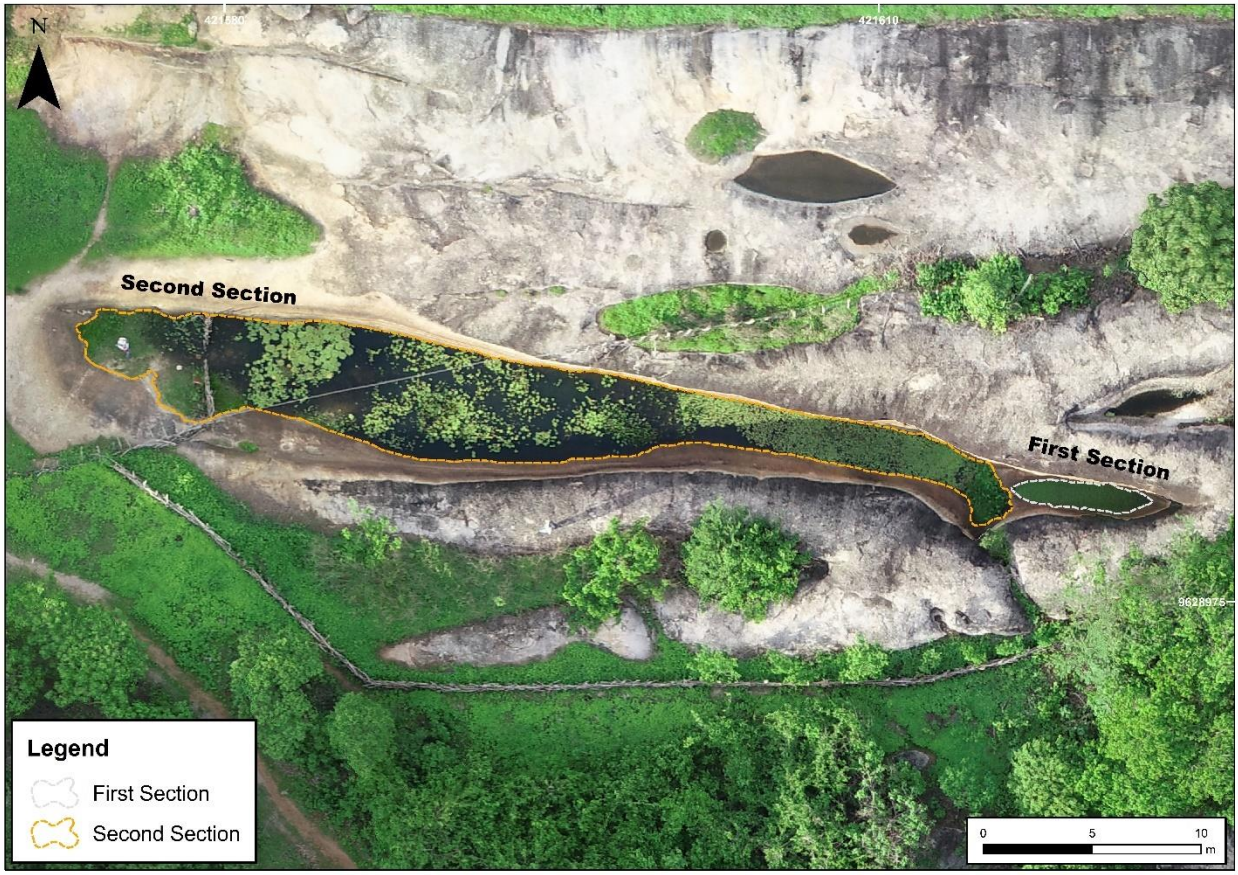

Figure 7. The Jirau 01 natural tank at the Jirau Paleontological site, partially covered by a water layer and the different sections of the depression highlighted. It is possible to observe the main axis, the fractures on the W-E (WNW-ESE)

direction and others on NW-SE direction, positioned obliquely at the Jirau 01 natural tank. In the downstream part (left side) it is possible to see the opening, or outlet, of the tank.

The first section is situated upstream to the natural tank, and presents the following dimensional parameters: 8 meters of length, with a maximum width of 1,5 meters and depth reaching 5 meters. The lateral walls of the natural tank are very steep, with plunges over 75º and, besides the pitting texture (a characteristic associated with chemical corrosion), present the active mechanism of plate disaggregation (flaking) on the top and middle portions of the cavity. The bottom morphology, where the sedimentary material was completely removed, has a concave format and is, apparently, over-excavated, with it being possible to identify the fracture as the preponderant structural factor to the natural tank development (Figure 8).

Figure 8. The first section of the Jirau 01 natural tank. A - Over-excavated bottom morphology of the tank; B - First section of the Jirau 01 natural tank. It is possible to observe the mechanism of flaking (plate disaggregation) on the lateral walls and the pitted texture (pitting) over the crystalline basement.

The second section corresponds to the segment located downstream to the natural tank. Thus, the continuity of the depressions holds, approximately, 45 meters in length, with a maximum width of 5,50 meters and depths up to 4 meters. The tank maintains on the WNW-ESE direction axis. On the lateral walls, it is possible to observe a differentiation in relation to the first section, due to the manner in which the top and middle parts of the lateral walls was lowered and smoothed (see Figure 9).

Figure 9. Second section of the Jirau 01 natural tank. A - It is possible to analyze the ruptile structure, in this case, the fracture, preponderant in the formation of the natural tank from the main axis. Aspect of the asymmetry between the tank lateral walls; B - Second section of the Jirau 01 natural tank. Detail of the opening or outlet of the natural tank, constrained by the granitic abutments and the *cacimbas* (water-holes) excavations over the tank deposit.

It is important to remark that, in the intersectional area between the fractures, a cluster of minor cavities also occurs, similar to the aspect of a "honeycomb". In general, these are commonly found in shelters or cavities of the tafone type, which can be the result of punctual efforts over the crystalline basement (VIDAL-ROMANÍ, 2008; VIDAL-ROMANÍ; UÑA ALVAREZ; VAQUEIRO RODRÍGUEZ, 2014a; VIDAL-ROMANÍ; VAQUEIRO RODRÍGUEZ; SANJURJO SÁNCHEZ, 2014b; VIDAL-ROMANÍ et al., 2018). The process in question might have favored the development of pre-established features which were modified by the weathering front and, later, under subaerial conditions. On the lateral walls it is also possible to see the action of the flaking mechanism, besides the texture associated to pitting. As it moves forward to outlet, the natural tank tends to grow wider until it forms a wide opening. When using specific terms on papers that involve granitic geomorphology, the opening on the natural tank can also be named as outflow (see Figure 9).

An important note regarding the Jirau 01 natural tank is that the depression has not been completely excavated. In the inside of the Jirau 01 natural tank, the remaining material found next to the outlet and which constitutes the tank deposit can be divided into three sedimentary facies from the bottom to the top (XIMENES, 2003; ARAÚJO-JÚNIOR, 2012; ARAÚJO-JÚNIOR et al., 2013; ARAÚJO-JÚNIOR, 2015), which are: (a) the basal level, composed of conglomeratic sandstone (1,5 meters thick), constituted by in situ weathered material from the matrix basement and sandy sediments; (b) the middle level constituted by conglomerates with sand-clayey matrix, where fossils are concentrated, deposited in a debris/mud flow context (1 meter thick); and (c) the top level lies constituted by fine sediments (1,5 meters thick), composed of clay and silt sediments, with eventual quartz pebbles and an abundance of organic material.

7. Discussions

One of the recent hypotheses being discussed in an academic environment, both for the origin of the parable-shaped tank (vertical symmetry from the main axis) and the occurrence of minor cavities on the lateral walls of the depression arises from the model of migration and concentration of charges in the subsurface. The Leucogranite Penedos lithological unit was allocated in depth at the Santa Quitéria Granitoid, under confining conditions, being subjected to magmatic cooling in different stages, followed by deformation phases of ruptile character and, later, to pressure relief (decrease on confining pressure or erosion of superjacent layers) throughout geological time. The set of processes previously exposed has been accepted in the academy as responsible for the origin and development of families or sets of fractures/joints (sheet fractures) in the crystalline basement (OLLIER, 1984; VIDAL-ROMANÍ, 1989, 2008; VIDAL-ROMANÍ; TWIDALE, 1999; VIDAL ROMANÍ et al., 1995; TWIDALE; VIDAL-ROMANÍ, 2005). The occurrence of fractures (sheet structure) over the granitic basement has been pointed as where the main entrance points to the development of processes linked to the chemical corrosion in subedaphic conditions. Thus, the establishment of meteoric water over specific areas, for instance, in fracture intersections, considering the proximity and disposition of the ruptile structures, would have allowed the acting and differential reshaping from the weathering front in subsurface. However, the sheet structure, besides resulting in the opening

of several entrance points for the access and establishment of meteoric waters, might also have originated the formation of numerous points of tectonic and/or atectonic processes. The charge concentration would result in pre-established structures, in this case, in internally deformed zones, similar to tension bulbs, which would act as preferential areas over the granitic basement to the weathering attacks on the subsurface.

In relation to the morphological aspects of the natural tank interior, it is possible to see a series of minor structures over the basement which would correspond, in international academic literature, to the forms linked to the process of physical-chemical corrosion derived from the soil-rock contact. The granite surface can be characterized, for instance, from a texture known as pitting, with active signs of granular disaggregation and/or flaking. On the lateral walls, it is possible to see the occurrence of minor cavities, similar to honeycomb forms found in features of the tafone type.

Due to the low porosity and permeability of the granitic basement, the natural tank, once exposed to subaerial conditions, should maintain the characteristics generated and/or reshaped in subsurface throughout geological time, setting in the Itapipoca landscape the occurrence (and permanence) of different levels, or even stages, of development of these natural depressions. Even though processes linked to the deepening and/or widening of the natural tank continue after the exposal, these would be subject to significantly slower rates in relation to subedaphic processes. In contrast, the processes of erosion and transportation would act more efficiently over the in situ regolithic material which previously covered the granite terrains, favoring the episodic exposal of the natural tanks. Thus, events associated with different erosive pulses, reoccurrence of torrential rains and relief dissection in the region might be linked to the partial removal of accumulated material in the interior of the depressions, generating accommodation spaces which would be then filled by Quaternary deposits with fossiliferous content from the prehistorical megafauna. The main processes linked to the continuity of the reshaping and erosion of the natural tank, in a subaerial environment, would happen through fluvial action, effects resulting from thermoclasty, influence of biological agents, aeolian activity, etc.

8. Final Considerations

In the context of tectono-structural control, the Jirau 01 natural tank corresponds to two interconnected depressions which apparently developed from the occurrence of ruptile structures over the granitic basement. The main axis of the tank is linked to a fracture in the WNW-ESE (N80W) direction, being crossed obliquely by another fracture in the N30W direction. Although it is highlighted in geological mapping that the intrusive bodies, with elongated shapes, are oriented towards the N45E direction (regional trend) (BRAGA; GOMES, 2018), the lineaments conjugation, in detail, preponderantly presents the WNW-ESE (or NW-SE) and NWN-SES directions.

In the first section, located upstream to the natural depression, the tank format is similar of a parable, being characterized by its concavity facing upwards and a vertical symmetry axis, while downstream, in the second section, the parable tends to become wider, lowering the tank edges or granitic abutments until it constitutes an outlet. It is important to remark that the lateral walls on the second section of the tank present a different reshaping, where the edges and granitic abutments are asymmetric, specifically from the point where the joining of fractures oblique and parallel to the main axis occurs. The initial observations in this present study aim to highlight, from the morphological analysis of the Jirau 01 natural tank, the preponderant role of structural control in the possible origin and development of the natural depression.

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