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Paleoenvironmental and Paleoecological Inferences of the Quaternary Megafauna of Lajedão do Patrício, Bahia, Brazil

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ABSTRACT

During the Pleistocene, a diverse fauna composed of large and mega mammals lived in the Northeastern of Brazil, and is generally associated with open environments. We present in this study carbon and oxygen isotopic data of *Notiomastodon platensis* and Toxodontinae from the fossiliferous deposit of Lajedão do Patrício, João Dourado, Bahia, Brazil. The analyzes of $\delta^{13}C$ and $\delta^{18}O$ were carried out to better understand the paleoecology of these taxa and, consequently, make it possible to obtain paleoclimatic and paleoenvironmental inferences about the region of Lajedão do Patrício fossiliferous deposit. The $\delta^{13}C$ values identified for *Notiomastodon platensis* (−5.67‰ and −6.95‰) and Toxodontinae (−5.62‰ and −7.03‰) indicate a mixed diet for these taxa due to the consumption of C_3 and C_4 plants, indicating an environmental scenario of vegetation mosaic of dry forest (*caatinga*) and cerrado during the Pleistocene/Holocene. The comparison between the $\delta^{13}C$ data from the megafauna in Northeast Brazil allowed the identification of opportunistic behaviors for *Notiomastodon platensis* and Toxodontinae, varying between the browser, mixed and grazing habits, according to the characteristics of the habitat in which they lived. The $\delta^{18}O$ data and its variations suggest changes in the precipitation regime during the Pleistocene/Holocene transition in the region of the analyzed fossiliferous deposit.

1. Introduction

During the Pleistocene, the Northeastern Brazil was inhabited by large endemic and exotic mammals (biomass> 44 kg) and giant mammals (biomass> 1,000 kg; *sensu* Cartelle, 1999). Some taxa from the Pampas region (southern continent) have migrated to the Northeast of Brazil at the end of the Pleistocene and beginning of the Holocene (Cartelle, 1999). These species have coexisted sympathetically with the endemic species, with these taxa being adapted to live in dry forest areas (savanna or steppe savana; Dantas et al., 2013).

The stable isotopic composition of mammalian teeth is directly related to the isotopic composition of their food items consumed (Lee-Thorp and van der Merwe, 1987; Cerling et al., 1997). Enamel and dentin are faithful file, whose isotopic composition can be used to indicate changes in the composition of the atmosphere, fraction of the biomass in the diet (C_3 or C_4 plants) of modern and fossil mammals, for identifying whether they are from closed or open habitats (Cerling and Harris, 1999). Thus, the isotopic composition of the tooth enamel of modern and fossil mammals has important applications in the reconstruction and interpretation of food source vegetation (Vogel et al., 1990; MacFadden and Cerling, 1996; Cerling et al., 1997).

In Northeastern Brazil, there are a large number fossils of Quaternary megafauna recovered from caves (e.g. Cartelle, 1992, 1999; Auler et al., 2006), lakes and tank deposits (e.g. Porpino et al., 2004; Alves et al., 2007; Araújo-Júnior et al., 2013; Asakura et al., 2016; Scherer et al., 2017; Faria and Carvalho, 2019). The fauna of these fossil concentrations is well known and diversified (Cartelle, 1999; Bergqvist and Almeida, 2004), showing the dominance of mega-mammals compared to other groups of vertebrates due to the action of taphonomic agents (Araújo-Junior et al., 2017; Faria et al., 2020a). However, in Brazil few studies of stable isotopes of skeletal remains of this fauna were performed, revealing important paleoecological and paleoenvironmental aspects (Sánchez et al., 2004; MacFadden, 2005; Viana et al., 2011; Dantas et al., 2013, 2017, 2017; França et al., 2014; Pasani et al., 2019; Silva et al., 2019). Thus, the main purpose of this work is to present and discuss $\delta^{13}C$ and $\delta^{18}O$ isotope data for *Notiomastodon platensis* and Toxodontinae, in order to infer paleoecological and paleoenvironmental aspects of Lajedão do Patrício fossiliferous deposit.

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2. Study area

The fossiliferous deposit of Lajedão do Patrício is located at Fazenda Faveleira, in the village of Lajedão do Patrício, João Dourado, Bahia, Brazil. Geographic location coordinates are 11° 16′ 52.4″ S, and 41° 35′ 79″ W Datum WGS 84 (Fig. 1A). This area is is mapped as Neo-Proterozoic metasedimentary carbonate rocks from the Salitre Formation, Nova América unit, which is characterized by finely laminated calcisiltites, calcilutites, and calcarenites (CPRM, 1985). In this fossil concentration, four taxa were identified: *Eremotherium laurillardi*, Toxodontinae indet., *Notiomastodon platensis,* and *Glyptotherium* sp., which correspond to a paucitaxic and multi-dominant assemblage (sensu Eberth et al., 2007).

Five layers were recognized in the sedimentary succession of Lajedão do Patrício (Fig. 1B). Layer 1 corresponds to a conglomerate with clasts and fossils presenting a flow direction (NW/SE to WSW/ENE), 40 cm thick, supported by muddy matrix. The taphonomic attributes identified in layer 1 were: disarticulated bones with a high degree of fragmentation, different weathering stages, and moderate abrasion. The skeletal remains were transported and accumulated by flash-floods in an environmental context with a low input of siliciclastic sediments with reworking phases, generating a densely packed fossiliferous concentration of complex taphonomic history (Faria and Carvalho, 2019).

Layer 2 (30 cm thick) is characterized by the deposition of pelitic sediments with signs of bioturbation and invertebrate remains (*Biomphalaria* sp.). Layer 3 (25 cm thick) is also characterized by the deposition of pelitic sediments, bioturbations, and invertebrates, however, of smaller size. Although layers 4 and 5 consists of a mixture of fine sand and mud, these were differentiated by the great presence of organic remains in layer 5. Layers 1–5 have the following colors according to the Munsell color chart 7.5Y8/2, 7.5Y5/1, 7.5Y4/1, 7.5Y7/3, and 7.5Y8/3, respectively.

3. Materials and methods

We obtained the isotopic composition (carbon and oxygen) of four fragments of teeth from the Quaternary megafauna (Fig. 1C), two assigned to *Notiomastodon platensis* (Notio-1 and Notio-2) and two

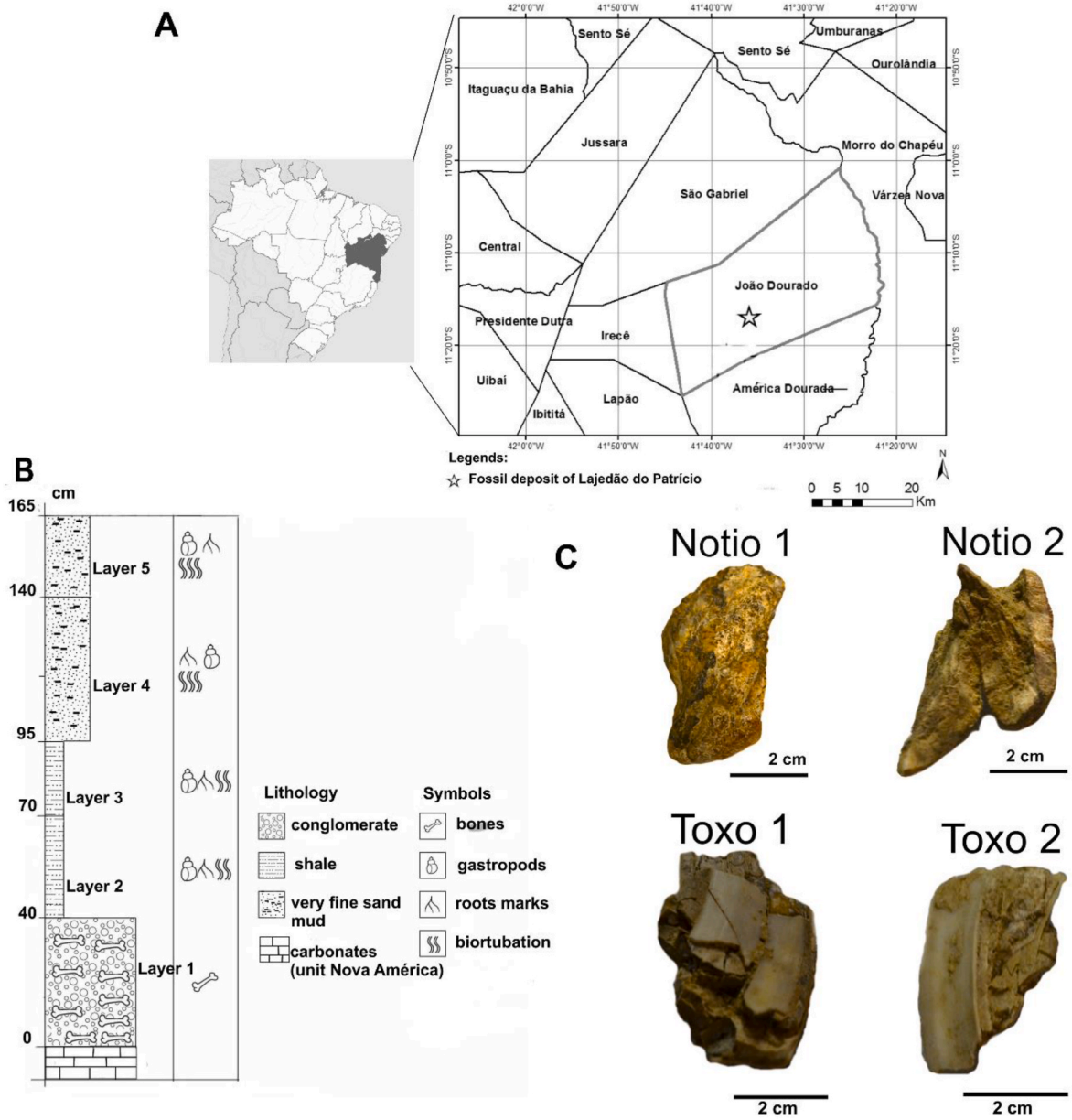

Fig. 1. A- Location map of the Lajedão do Patrício fossiliferous deposit; B- Stratigrafic profile of the Lajedão do Patrício deposit; C- samples of teeth analyzed.

assigned to Toxodontinae indet. (Toxo-1 and Toxo-2), recovered from the fossiliferous deposit of Lajedão do Patrício. We chose only to use dental enamel, due to its compact nature and less susceptible to diagenetic changes in the signals $\delta^{13}C$ and $\delta^{18}O$, than dentin and bones. (Wang and Cerling, 1994).

In the laboratory of the Universidade Sagrado Coração (São Paulo State), the material was immersed in ultrapure water (Milli-Q, Millipore) to remove the associated sediments, and then subjected to heat treatment by freezing in liquid nitrogen and thawing at room temperature, to separate the enamel from the dentine (Kinoshita et al., 2008). After these procedures, the specimens were sent to Laboratório de Análise de Minerais e Rochas of the Universidade Federal do Paraná (LAMIR-UFPR), for analysis of stable isotopes $\delta^{13}C$ and $\delta^{18}O$.

Spectrometry is performed on CO_2 released from the digestion of carbonates at 72 °C with orthophosphoric acid, in the online configuration using the gas preparer GasBench II. The results were referenced to the VPDB scale, using the reference materials NBS 19, IAEA–CO–8 and IAEA–CO–9. The standard deviation reported (1σ) refers to the internal deviation of 8–10 readings of the same preparation. These samples were previously dated by Faria et al. (2020b), using the ESR method (Electron Spin Resonance).

The data from the $\delta^{13}C$ were used to infer the diet of the fossil mammals *Notiomastodon platensis* and Toxodontinae indet. These taxa have different rates of isotopic enrichment based on their body mass, where *Notiomastodon platensis* presents 15‰ enrichment and 14‰ Toxodontinae in bone tissues (Tajeda-Lara et al., 2018). The estimated body mass for *N. platensis* is 6,000 kg and Toxodontinae 3,090 kg (Dantas et al., 2017). Thus, $\delta^{13}C < -11‰$ indicates a diet composed exclusively of C_3 plants (browser), where values of $\delta^{13}C > +3‰$ indicates a diet composed exclusively of C_4 plants (grazing), with values of $\delta^{13}C$ between −11‰ and +3‰ characterizes a mixed diet composed of C_3 and C_4 plants (MacFadden et al., 1999; MacFadden, 2005). For taxa with a mixed diet, we use the equation by Koch et al. (1998): $\delta\ ^{13}C_{enamel} = [\delta\ ^{13}C_{exclusive\ C4}\ x\ (X)] + [\delta\ ^{13}C_{exclusive\ C3}\ x\ (1\text{-}X)]$; where X = percentage of C_4 vegetation, to infer the percentage of C_4 vegetation consumed.

Grazing animals generally have higher $\delta^{18}O$ values than browser animals and mixed diet animals (Kohn et al., 1996; Helliker and Ehleringer, 2000). Thus, the association of both values of carbon and oxygen allows to verify which parts of C_3 plants were consumed, by animals with mixed or browser diet. Animals with C_3 plants in their diets can be divided into three categories by the oxygen value, which are: $\delta^{18}O < -1.3\%$ indicates consumption of forest floor plants, $\delta^{18}O$ close to 0.6% suggest a frugivore diet, where $\delta^{18}O > 2.1\%$ a folivore diet (Nelson, 2013).

Traditionally, the variation of $\delta^{18}O$ in terrestrial environments has been attributed to changes in the precipitation regime (Rozanski et al., 1993; MacFadden and Higgins, 2004), where hot climates result in $\delta^{18}O$ enrichment and cold weather in the decrease of $\delta^{18}O$ in meteoric water (Bryant et al., 1996). At low latitudes the values of $\delta^{18}O$ show a reverse sign in both hemispheres, with more negative values during the summer, in these latitudes the values of $\delta^{18}O$ are controlled by the amount of precipitation and, therefore, more negative during the rainy season (summer; Vuille et al., 2003). The $\delta^{18}O$ data obtained from the teeth of Lajedão do Patrício were analyzed, according to Vuille et al. (2003), and compared with the $\delta^{18}O$ data from Northeastern Brazil for the last 210 ka (Wang et al., 2004; Cruz et al., 2009; Stríkis et al., 2018), to see if these values are in correspondence.

4. Results

The values of $\delta^{13}C$ and $\delta^{18}O$ obtained for *Notiomastodon platensis* and Toxodontinae indet. from Lajedão do Patrício are shown in Table 1. The values of the $\delta^{13}C$ indicating a mixed diet (C_3 and C_4 plants). Through the equation of Koch et al. (1998) we identified the following values (X% C4; Table 1) for the analyzed taxa, where was possible to infer that these species consumed similar proportions of C_3 and C_4 plants in their diets.

Table 1
Analysis of $\delta^{13}C$ and $\delta^{18}O$ and dating by ESR (Faria et al., 2020b) of fossil teeth from Lajedão do Patrício.

Taxon	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)	X (% C_4)	Age (ka)
N. platensis (Notio-1)	−5.67	−3.47	52%	16.8 ± 2.6
N. platensis (Notio-2)	−6.95	−4.35	43%	12.5 ± 2.3
Toxodontinae (Toxo-1)	−5.62	−5.57	53%	9.6 ± 1
Toxodontinae (Toxo-2)	−7.03	−6.25	42%	9.1 ± 1

5. Discussion

5.1. $\delta^{13}C$: Paleoecological and paleoenvironmental inferences

Through pollen data, a predominance of vegetation adapted to the climate was identified, such as the Caatinga and Cerrado, between 42 ka and 8.5 ka for the Northeastern of Brazil. This signal was interrupted by short wet periods at 40 ka, 33 ka, 24 ka and between 15.5 ka and 11.8 ka, represented by the expansion of tropical forest and galleries over areas of *Caatinga* and *Cerrado* (De Oliveira et al., 1999; Behling et al., 2000). The *Caatinga* biome is classified as Seasonally Dry Tropical Forest (SDTF; Mooney et al., 1995; Pennington et al., 2006). This type of plant formation is marked by prominent seasonal rains with months of intense drought, the vegetation being quite heterogeneous with formations ranging from high forests (deciduous and semi-deciduous), shrub, and fields. Therefore, when we use the term closed environments in this analysis, it refers to the formations of tropical forest, gallery, arboreal and shrubland *Caatinga*; and open environments refers to grass and herbaceous vegetation.

The results obtained for $\delta^{13}C$ from the enamel of *N. platensis* and Toxodondinae from Lajedão do Patrício indicate a mixed diet, with similar proportions of C_3 and C_4 plants (Table 1). It was also identified a mixed diet for *N. platensis*, for the municipality of Ourolândia (150 km far from Lajedão do Patrício), with very similar values $\delta^{13}C$ (−8.2‰ and −5‰; Sánchez et al., 2004)). Similar values were also identified ($\delta^{13}C$ −5.5‰) for Pedra Vermelha in Northeastern Bahia for *N. platensis*, and more negative ($\delta^{13}C$ values (−12.6‰ and −7.7‰) for Toxodontinae from Ourolândia, identifying a mixed and browser diet for this taxon in the central-northern region of Bahia (MacFadden, 2005). Dantas et al. (2013) identified very depleted carbon isotope values for *T. platensis* ($\delta^{13}C$ −13.24‰) in Vitória da Conquista, Bahia State, indicating a browser diet; for *N. platensis* from Coronel João Sá, Bahia State, values were identified ($\delta^{13}C$ −1.04‰ and $\delta^{13}C$ −0.49‰) more enriched, indicating a grazing diet with small proportions of C_3 plants. For the locality of Lagoa da Pedra (Anagé - Bahia; Silva et al., 2019) the taxon *N. platensis* presents values very similar to those identified for Lajedão do Patrício, indicating a mixed diet for this taxon for the compared locations.

Based on the compilation of isotopic values ($\delta^{13}C$) found for *T. platensis* and *N. platensis* for different locations in Bahia (Sánchez et al., 2004; MacFadden, 2005; Dantas et al., 2013; Silva et al., 2019; Pasani et al., 2019), we observed that these taxa have a mixed diet, with different proportions of C_3 and C_4 plants. The isotopic values exposed previously, when compared to other locations of the BIR (Viana et al., 2011; Dantas et al., 2013, 2017, 2017; França et al., 2014; Pasani et al., 2019) and the South of Brazil (Lopes et al., 2013), suggest a generalist diet for both taxa, allowing them an ecological plasticity which favored them to occupy different habitats in Brazil.

The isotopic values identified for *N. platensis* and *Toxodon* indicate a generalist habit, with these taxa varying ecologically from browser, mixed and grazing in different regions of the American continent. MacFadden (2005) identified intermediate values for *Toxodon* from Honduras ($\delta^{13}C$ −9.7‰), Buenos Aires/Argentina ($\delta^{13}C$ −8.7‰), and northeastern Brazil ($\delta^{13}C$ −8.6‰), indicating a mixed diet for this one.

Sánchez et al. (2004) interpreted that *N. platensis* had a wide range of dietary adaptations for the taxon, with a browser diet in the province of Buenos Aires/Argentina, mixed and grazing in Northeast Brazil, and exclusively grazing in the La Carolina Peninsula/Ecuador.

Thus, *Notiomastodon platensis* in the central-northern region of Bahia presents a mixed diet, where Toxodontinae presents a mixed and browser diet. From the $\delta^{13}C$ values obtained for these taxa, we can infer a mosaic of arboreal and shrub vegetation with areas of grass vegetation, for the region of the fossiliferous deposit of Lajedão do Patrício. When we associate the results obtained here with those of Sánchez et al. (2004) and MacFadden (2005), it is possible to infer a paleoenvironmental scenario very similar to that of Lajedão do Patrício, for the central-northern region of Bahia, with gallery forest, arboreal and shrubland areas with grassy zones, due to the $\delta^{13}C$ values of *Notiomastodon platensis* ranging from - 8.2‰ to −5‰, and Toxodontinae from - 12.6‰ to −5.5‰, respectively (Sánchez et al., 2004; MacFadden, 2005; Dantas et al., 2013, 2017).

We identified a relatively high variation of 1.28‰ between the $\delta^{13}C$ values for the *Notiomastodon platensis* samples (Table 1), in a period of approximately 4.3 ka, indicating a greater participation of C_3 vegetation in the diet of this taxon and, consequently, indicating a possible expansion of closed environments in the Lajedão do Patrício fossil deposit. The most negative values of $\delta^{13}C$ in Notio-2 (Table 1) coincide with a period (15.5 ka to 11.8 ka) of higher humidity identified by Behling et al. (2000), characterized by the expansion of wet and dry forests over open environments in Northeast Brazil.

We also identified a relatively high variation of $\delta^{13}C$ (1.4‰) for Toxodontinae in a period of approximately 0.5 ka, also indicating greater participation of C_3 plants in the diet of this taxon, and also, expansion of closed environments over grassy areas. De Oliveira et al. (1999) identified a gradual increase in humidity and temperature conditions in the central region of Bahia State between 10.5 ka and 8.9 ka, due to the expansion of gallery forest over areas of caatinga and cerrado and the disappearance of montane taxa. This corroborates the hypothesis of expansion of dry forest over open environments, for the region of Lajedão do Patrício fossiliferous deposit. Therefore, the different values of $\delta^{13}C$ obtained and their variations, when associated with their respective ages, indicate different environmental conditions for Lajedão do Patrício fossiliferous deposit.

5.2. $\delta^{13}C$: Biogeographic aspects of northeastern Brazil

We compared the $\delta^{13}C$ values obtained for Lajedão do Patrício (Table 1), with other localities in Northeastern Brazil (Sánchez et al., 2004; MacFadden, 2005; Silva, 2009; Viana et al., 2011; Dantas et al., 2013, 2017). In this way, different alimentary habits are identified for the Quaternary megafauna (grazing, mixed and browser), confirming the hypothesis of generalist behavior, raised by Dantas et al. (2013). In Fig. 2, we can see a grouping of similar alimentary habits in different latitudes in BIR, indicating a possible biogeographic distribution of open and closed environments in Northeast of Brazil, with regions with different vegetational characteristics (Fig. 3): A (Rio Grande do Norte), B (Alagoas, Sergipe and Centro-Norte da Bahia) and C (South Bahia).

In the Center-North and Northeast of Bahia, *Notiomastodon platensis* presents values of $\delta^{13}C$ ranging from −8.2‰ to - 1.04‰ (Sánchez et al., 2004; Dantas et al., 2013; our data), indicating a mixed diet with different proportions of C_3 and C_4 plants. The $\delta^{13}C$ values of Toxodontinae for this region vary from −12.6‰ to - 1‰, indicating browser, mixed and grazing habits for this species (MacFadden, 2005; Dantas et al., 2013). Dantas et al. (2017) identified similar values of $\delta^{13}C$ (−13.2‰) for *Eremotherium laurillardi* in Quijingue (Bahia State). Through this, we can postulate that *Notiomastodon platensis*, Toxodontinae, and *Eremotherium laurillardi* tend to feed more on C_3 plants closed environments and, in open environments, they present a diet based on C_4 plants. This shows that these species had opportunistic behavior, feeding according to the vegetation characteristics offered by the environment. Therefore, these variations in the $\delta^{13}C$ values of these taxa for region B indicate a vegetation mosaic with dry forests (*Caatinga*), gallery forest and open areas.

When comparing the groupings obtained in Fig. 2, with maps of

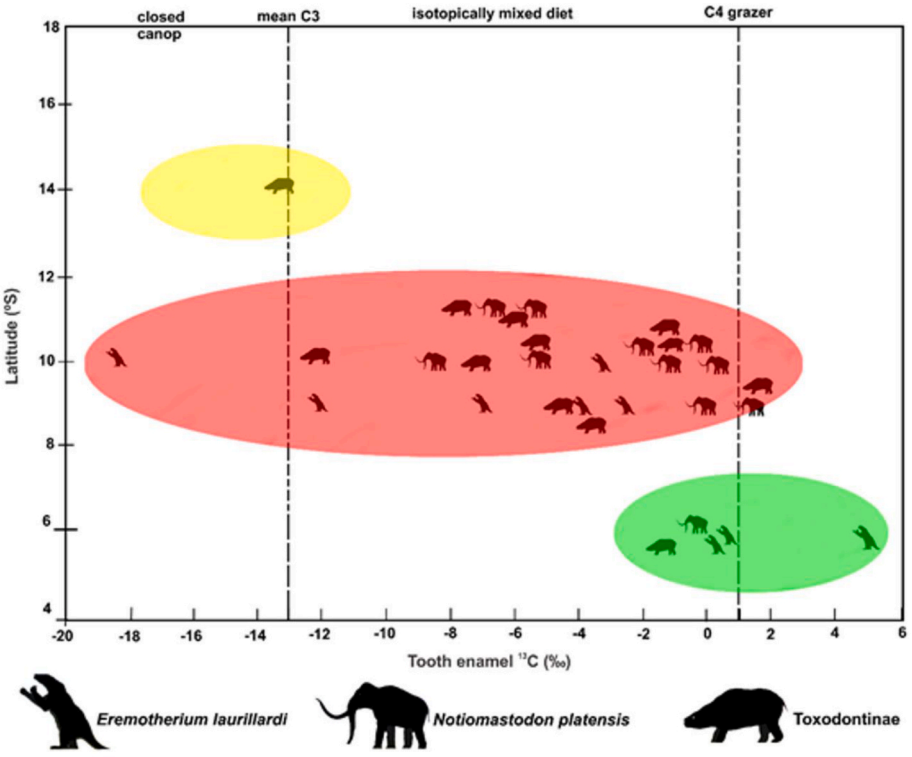

Fig. 2. Relationship among latitude and carbon isotope ($\delta^{13}C$ ‰) for Northeast Brazil (the values were extracted from Sánchez et al., 2004; MacFadden, 2005; Silva, 2009; Dantas et al., 2013, 2017; Scherer et al., 2017; and our data).

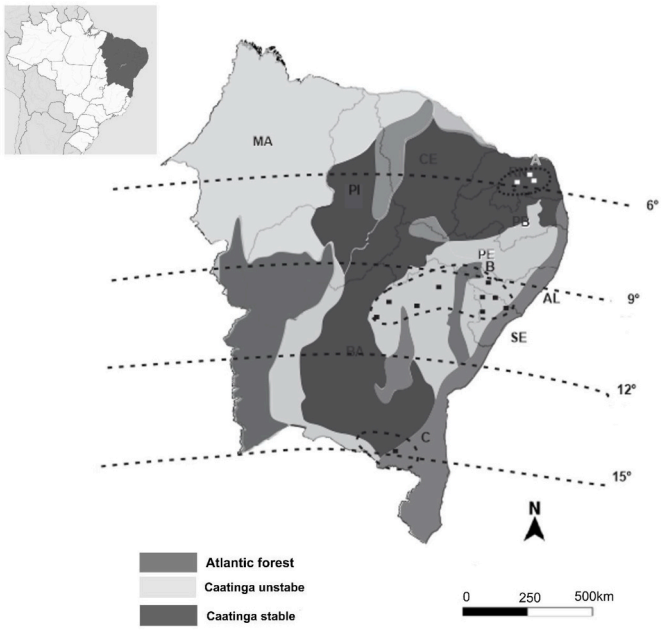

Fig. 3. Map of Northeast Brazil, showing the potential distribution of Atlantic Forest and Tropical Dry Forest (modified from Carnaval and Moritz (2008) and Werneck et al. (2011). A-represents the region that includes the municipalities of Rui Barbosa, Barcelona and Currais Novos in the state of Rio Grande do Norte; B- region that includes the municipalities of João Dourado (BA), Coronel João Sá (BA), Morro do Chapéu (BA), Ourolândia (BA), Quijingue (BA), Poço Redondo (SE), Canhoba (SE) and Maravilha (AL).

distribution of the vegetation of Atlantic Forest (Carnaval and Moritz, 2008) and dry forest (savanna or steppe savanna; Werneck et al., 2011) comprising the last 21 ka resulted in Fig. 3. We observed that the geographic pattern previously inferred is very similar to that inferred by Dantas et al. (2013), for *Notiomastodon platensis*, *Eremtherium laurillardi* and Toxodontinae (Fig. 2) has a strong correlation with the potential distribution map of Atlantic Forest and Dry Forest (Fig. 3), presenting different habits according to the vegetation presented by the environment. Therefore, these species were present both in open and closed environments, as also observed by Dantas et al. (2013), and cannot be used as indicators of the presence of open environments, as previously postulated by Rossetti et al. (2004).

5.3. $\delta^{18}O$ and paleoclimatic inferences

The isotopic oxygen values identified for *N. platensis* and Toxodontinae (Table 1) indicate that they consumed C_3 plants from the forest bottom (Nelson, 2013). Dantas et al. (2017) identified that *N. platensis* is necessarily a drinker, implying that the isotopic oxygen values of this taxon are in isotopic equilibrium with water bodies. The same authors propose that *T. platensis* obtained a large part of their water from the food consumed. In this way, the isotopic oxygen values found for the analyzed taxa cannot be directly compared, allowing only comparisons with istopic values of the same taxon. Due to the different sources of ^{18}O for the taxa analyzed in Lajedão do Patrício it indicates that they did not compete directly for C_3 plant resources, which indicates that they competed for C4 plant resources. For BIR, an overlap in the amplitude of the niches of these taxa was identified, indicating that they competed for C_4 plant resources (Dantas et al., 2017).

When comparing the values of δ18O obtained and their respective ages (Table 1), with the paleoclimatic curves obtained for Northeast Brazil from the last 210 ka (Wang et al., 2004; Cruz et al., 2009; Stríkis et al., 2018) shown in Fig. 4. It can be seen that the δ18O values obtained for *Notiomastodon platensis* and Toxodontinae from Lajedão do Patrício have strong correspondence.

The $\delta^{18}O$ values of *Notiomastodon platensis* show a variation of 0.88‰, indicating possible changes in the precipitation regime for the region of the fossiliferous deposit of Lajedão do Patrício. The most positive sign of Notio-1 (Table 1) coincides with a period of abrupt changes in dry and wet conditions between 17.3ka and 16.4ka identified by Cruz et al. (2009). Thus, the more positive $\delta^{18}O$ value of the Notio-1 sample compared to Notio-2 (Table 1), may be associated with dry climatic conditions within this period. Thus, the more positive $\delta^{18}O$ value of the Notio-1 sample compared to Notio-2 (Table 1), may be associated with dry climate conditions within this period, where Notio-2 age coincides with a period of humid climate between 15.5 ka and 11.8 ka, identified by Behling et al. (2000).

According to these authors, this is the wettest period recorded in the Northeast during of the late Quaternary, due to the expansion of gallery forests allowing floristic exchanges between Atlantic and Amazonian forests. Therefore, the variation in the $\delta^{18}O$ values between the *Notiomastodon platensis* samples (Table 1) indicates more humid conditions for this period, these data, even though occasional, indicate that the hypothesis of expansion of closed over open environments for the region of the fossiliferous deposit of Lajedão do Patrício, is in agreement with Behling et al. (2000).

Toxodontinae samples also show little variation in $\delta^{18}O$ values of 0.68‰ (Table 1), indicating a possible increase in humidity levels during the initial Holocene. De Oliveira et al. (1999) identified a marked decrease in wind activity in the fossil dune field of the middle São Francisco River valley (Bahia) in the period between 10.5 ka and 9 ka, due to the increase in humidity levels, and also to the disappearance of taxa and expansion of gallery forest vegetation over areas of caatinga and cerrado. Thus, the more negative values of $\delta^{18}O$ for Toxo-2 than Toxo-1 (Table 1) indicate the hypothesis raised in the previous section of expansion of dry forests over open environments during the Initial Holocene for the Lajedão do Patrício region.

The most negative value of $\delta^{18}O$ in the Toxo-1 sample compared to Toxo-2 (Table 1), although these are related to a wetter period for the Northeast of Brazil, according to Behling et al. (2000) and Cruz et al. (2009), may be associated with a progressive increase in temperature that marks the Pleistocene/Holocene transition. Stute et al. (1995) through analysis of noble gases from aquifers in Piauí (Cabeças and Pimenteiras), identified that the average temperature between 35 ka and 10 ka was 5.4° ± 0.6 °C lower than the average temperature during the Holocene. These more negative $\delta^{18}O$ values for Toxodontinae samples (Table 1), due to their Holocene ages, may result from the Amount Effect (Rozanski et al., 1993), generating more depleted $\delta^{18}O$ signals due to the increase in temperature.

The main result of the Amount Effect is that when there is a significant increase in temperature and a significant humidity, as identified for the initial Holocene of Northeast Brazil (Stute et al., 1995; De Oliveira et al., 1999), the values of $\delta^{18}O$ in meteoric water becomes more negative (Vuille et al., 2003). Therefore, the $\delta^{18}O$ values obtained for *Notiomastodon platensis* and Toxodontinae from the fossiliferous deposit of Lajedão do Patrício, have a direct relationship with the environmental and climatic changes that occurred in the Northeast during the Pleistocene/Holocene, indicate the hypothesis of vegetation changes attributed to different paleoenvironmental conditions and paleoclimatic.

6. Conclusions

In the region of the fossiliferous deposit of Lajedão do Patrício, *Notiomastodon platensis* and Toxodontinae present mixed diet consuming similar amounts of C_3 and C_4 plants, indicating a vegetation mosaic with areas of arboreal and shrubland and areas of grasses and herbs. This inferred paleoenvironmental and paleoecological scenario is very similar to the scenarios inferred by other authors for the central-northern region of Bahia. Through the different values of $\delta^{13}C$ and their respective ages, and also, through palynological data indicates a possible expansion of closed environments (forest of galleries, tree and

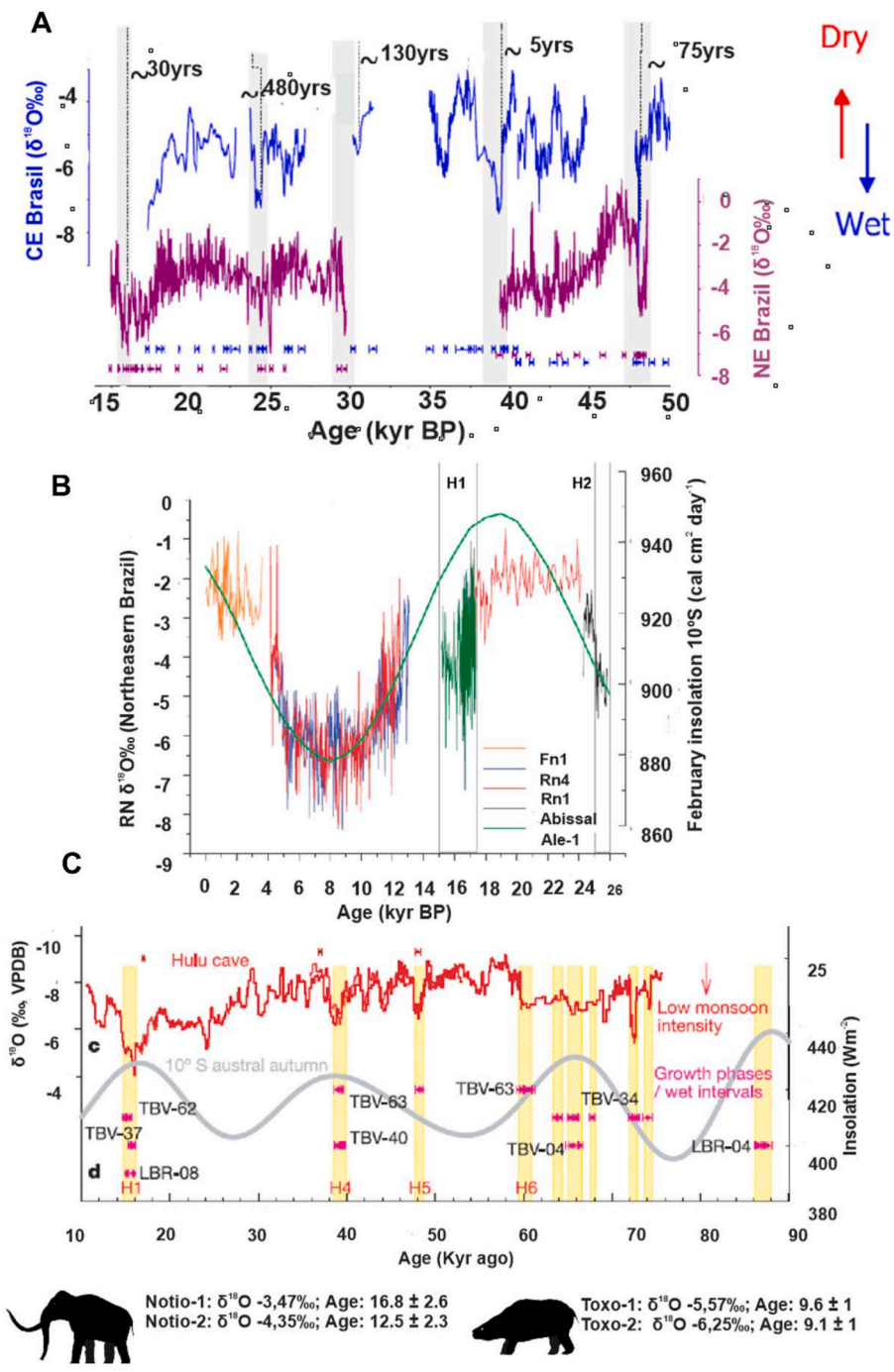

Fig. 4. Paleoclimatic record obtained through $\delta^{18}O$ analysis of speleothems in caves of the Northeastern Brazil. (A) Paleo monsoon reconstruction from CE (Eastern Central) and Northeaster from Brazil Stríkis et al. (2018); (B) paleoclimatic record of caves in Rio Grande do Norte, Brazil, where H1 and H2 are identified as events of Heinrich millennial-scale (modified from Cruz et al., 2009); (C) speleothems growth patterns of the region Chapada Diamantina/BA, the growth intervals are shown pink dots.

shrub scrub) over open environments (grasses and herbaceous), which coincide with environmental changes on a regional scale.

The results obtained from $\delta^{18}O$ and their respective ages corroborate the hypothesis raised and inferred through the $\delta^{13}C$ data from *Notiomastodon platensis* and Toxodontinae from Lajedão do Patrício. The $\delta^{18}O$ values of the enamel of fossil teeth from Lajedão do Patrício, in comparison with oxygen isotopic data from speleothemes, allow us to suggest to be an important indicator of changes in the precipitation regime. Therefore, through the analysis of $\delta^{13}C$ and $\delta^{18}O$ and others evidence, it was possible to identify different paleoenvironmental and paleoecological scenarios for the region of the fossiliferous deposit of Lajedão do Patrício.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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