Journal of South American Earth Sciences 112 (2021) 103616

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

ESR dating of *Toxodon* teeth from Baixa Grande, Bahia, Brazil

Ricardo da Costa Ribeiro [a], Angela Kinoshita [b,*], Hermínio Ismael de Araújo-Júnior [c], Ana Maria Graciano Figueiredo [d], Ismar de Souza Carvalho [a,e], Oswaldo Baffa [f]

[a] Departamento de Geologia, Instituto de Geociências, Universidade Federal Do Rio de Janeiro, Rio de Janeiro, Brazil
[b] Pró-Reitoria de Pesquisa e Pós-graduação, Universidade Do Oeste Paulista, São Paulo, Brazil
[c] Departamento de Estatigrafia e Paleontologia, Faculdade de Geologia, Universidade Do Estado Do Rio de Janeiro, Rio de Janeiro, Brazil
[d] Instituto de Pesquisas Energéticas e Nucleares, IPEN, São Paulo, São Paulo, Brazil
[e] Centro de Geociências, Universidade de Coimbra, Coimbra, Portugal
[f] Departamento de Física, Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto, Universidade de São Paulo, Ribeirão Preto, São Paulo, Brazil

ARTICLE INFO

Keywords:
Toxodon platensis
ESR dating
Megafauna

ABSTRACT

Although the extinct Quaternary megafauna is widely recorded in northeastern Brazil, geochronological studies carried out on its fossiliferous deposits are still scarce. In this study, Electron Spin Resonance (ESR) was applied to date 12 tooth fragments of *Toxodon platensis* (Mammalia, Notoungulata) collected in the tank deposit of Lago do Rumo, Baixa Grande, state of Bahia, Brazil. The results obtained in the geochronological analysis performed here reveal ages from around 60 ka to 34 ka for *T. platensis* in Lagoa do Rumo; and, considering the integration data in the paleontological literature, our results evidence the largest time-averaging ever recorded for tank deposits: around 51 thousand years.

1. Introduction

The extinct Quaternary megafauna is widely recorded in northeastern Brazil (Ribeiro, 2008). However, the geochronological studies carried out on its fossiliferous deposits are still scarce. Some results were obtained from Electron Spin Resonance (ESR) datings on fossils from Paraíba (Puxinanã) (Kinoshita et al., 2005a, 2005b), Pernambuco (Brejo de Madre de Deus) and Alagoas states (Oliveira et al., 2010). Radiocarbon (^{14}C) datings were performed in fossils recovered from tank deposits from Bahia (Quijingue, Vitória da Conquista and Coronel João Sá), Sergipe (Poço Redondo) and Rio Grande do Norte (Rui Barbosa and Currais Novos) states (Dantas et al., 2013; Drefahl, 2010). Other absolute datings were obtained through U–Th series and ^{14}C dating on fossils and calcite ($CaCO_3$) collected from speleothems associated with bioclasts from the cave deposits of Chapada Diamantina, Bahia (Auler et al., 2006; Czaplewski and Cartelle, 1998), and by ^{14}C in sediment associated with fossils from karst of Serra da Capivara, Piauí (Faure et al., 1999; Peyre et al., 1998). Usually, megafauna has been associated with Pleistocene deposits, with few occurrences in the Holocene (Baffa et al., 2000; Faure et al., 1999; Piló and Neves, 2003; Ribeiro, 2010).

The scarcity of geochronological data for the Quaternary megafauna of northeastern Brazil and the limited taphonomic studies of the fossil assemblages from where these fossils were recorded, evidence a path for new paleontological research related to this paleomastofauna, aiming to understand its temporal distribution and forms of preservation, thus contributing to solve issues related to its ecology and extinction. This study provides new ESR datings for the specimens of the notoungulate *Toxodon platensis* recovered from a tank deposit in northeastern Brazil, contributing for the knowledge on: (i) temporal distribution of this species in the Brazilian Intertropical Region; and (ii) time interval of the origin of bonebeds in tank deposits.

1.1. Studied area

The Lagoa do Rumo paleontological site (11°32′07″S; 40°07′11″W) is located at the municipality of Baixa Grande, Bahia State, northeastern Brazil (Fig. 1A). We recognize the sedimentary deposit as a tank deposit because it is a small sedimentary body that fill a natural depression in a basement rock in northeastern Brazil (Araújo-Júnior et al., 2013). These sedimentary deposits preserve remains of representatives of the Quaternary megafauna, including giant ground sloths, glyptodonts, gomphotheres, toxodonts, saber-toothed cats and macraucheniids.

In the case of Lagoa do Rumo, the taphocoenosis is composed of remains attributed to the mammals *Eremotherium laurillardi* (Pilosa,

* Corresponding author.
E-mail addresses: angela@unoeste.br, angelamitie@gmail.com (A. Kinoshita).

https://doi.org/10.1016/j.jsames.2021.103616
Received 23 July 2021; Received in revised form 18 October 2021; Accepted 25 October 2021
Available online 28 October 2021
0895-9811/

Megatheriidae), *Panochthus greslebini* (Cingulata, Glyptodontidae), *Glyptodon* sp. (Cinulata, Glyptodontidae), *Pampatherium* sp. (Cingulata, Pampatheriidae), *Toxodon platensis* (Notoungulata, Toxodontidae), *Notiomastodon platensis* (Proboscidea, Gomphotheriidae) and *Tayassu* sp. (Perissodactyla, Tayassuidae) (Ribeiro, 2014).

The sedimentary succession of Lagoa do Rumo paleontological site is composed of three layers measuring a total of 3 m (Fig. 1B) and directly overlying the crystalline rock basement. The fossils are found only at the basal one (layer 1), a 1 m, thickly bedded fossiliferous breccia with clasts and bioclasts cemented together. Above this layer there is a 10 cm-thick unfossiliferous sandy sediment. Upon the layer 2, a muddy sediment is observed (layer 3). The fossil assemblage is densely packed, mostly in direct contact with each other, poorly sorted, with a wide grain-size of the clasts and bioclasts, in a polymodal distribution, without a preferential orientation. The deposition was probably related to the hydrological dynamics of a debris flow during transportation from the source area to the tank (Ribeiro, 2014), similarly to the interpretation for other tank deposits in northeastern Brazil (Araújo-Júnior et al., 2013; Ribeiro, 2014).

2. Material and methods

Twelve teeth fragments identified as belonging to *Toxodon platensis* (Notoungulata, Toxodontidae) were dated by ESR (Fig. 2).

Initially, each specimen was immersed in water to remove the associated sediment. The solution obtained was centrifuged and dried in an oven for recover the sediment.

Afterwards, the teeth specimens were submitted to a thermal treatment, through freezing in liquid nitrogen and thawing at room temperature. After a few repetitions, the enamel detached from the dentin. This procedure has been adopted previously (Kinoshita et al., 2008b).

The enamel was subjected to a 1:5 acid treatment (HCl) in an ultrasonic bath to remove the outer layer of both sides. Thickness before and after treatment was recorded. After drying, the enamel was crushed manually with agate mortar and pestle to form a powder with particles of diameter $\varphi < 0.5$ mm.

The dentin and the associated sediment were also crushed. The sediment was split in three parts and, together with the enamel, was submitted to NAA to determine the concentration of radioisotopes (U, Th and K).

The spectrum of each sample was recorded on the JEOL FA-200 X-Band ESR spectrometer and compared to that of a bovine enamel sample, previously irradiated with a known dose (150 Gy) for rough evaluation of the equivalent dose (D_e). Subsequently, 10 aliquots of about 70 mg were selected from each tooth, and each aliquot was irradiated with a different dose, ranging from 50 to 1200 Gy.

After recording the spectrum of all aliquots, the peak-to-peak intensity of the dosimetric signal in $g_{\perp}$ was associated with the additive dose for the construction of the dose-response curve.

The equivalent dose (D_e) was determined through the fitting with single exponential function (1) (Ikeya, 1993):

$$I = I_0\left\{1 + e^{-\left[\frac{(D+D_e)}{D_0}\right]}\right\} \tag{1}$$

I represents the ESR signal amplitude, ***D***, the added dose. $\boldsymbol{I_0}$ and $\boldsymbol{D_0}$ the values of Intensity and Dose at saturation, respectively.

The D_e was converted into dating through the ROSY ESR Dating software (Brennan et al., 1999) using the concentration data of the radioisotopes present in the sample and sediment. It was adopted the value of 190 μGy/year as cosmic radiation rate, a value found after correction, taking into account the coordinates 11°32′07″S and 40°07′11″W, altitude (386 m) and the depth of the collection site (Prescott and Hutton, 1994). Sediment moisture was considered at 11%.

3. Results

Fig. 3A shows the ESR spectrum of specimen 1 irradiated with a dose of 500 Gy, demonstrating how the amplitude of ESR spectra were quantified. Fig. 3B shows the dose response curve that associates the spectrum amplitude with the additive dose of specimen 1. The fitting of experimental points with Eq. (1) gives the Equivalent Dose (D_e). The results of D_e and radioisotope concentrations in samples, measured

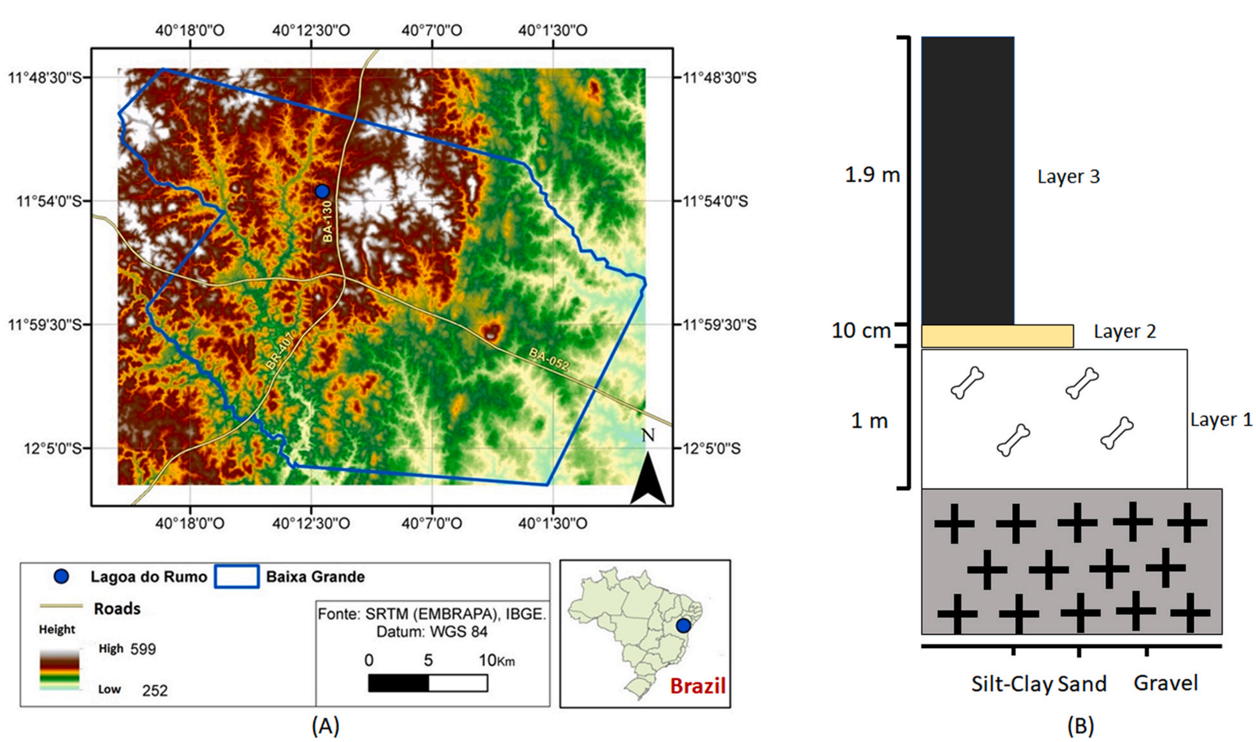

Fig. 1. (A) Elevation map of Baixa Grande showing the location of Lagoa do Rumo. (B) Stratigraphy of the fossiliferous deposits of Lagoa do Rumo.

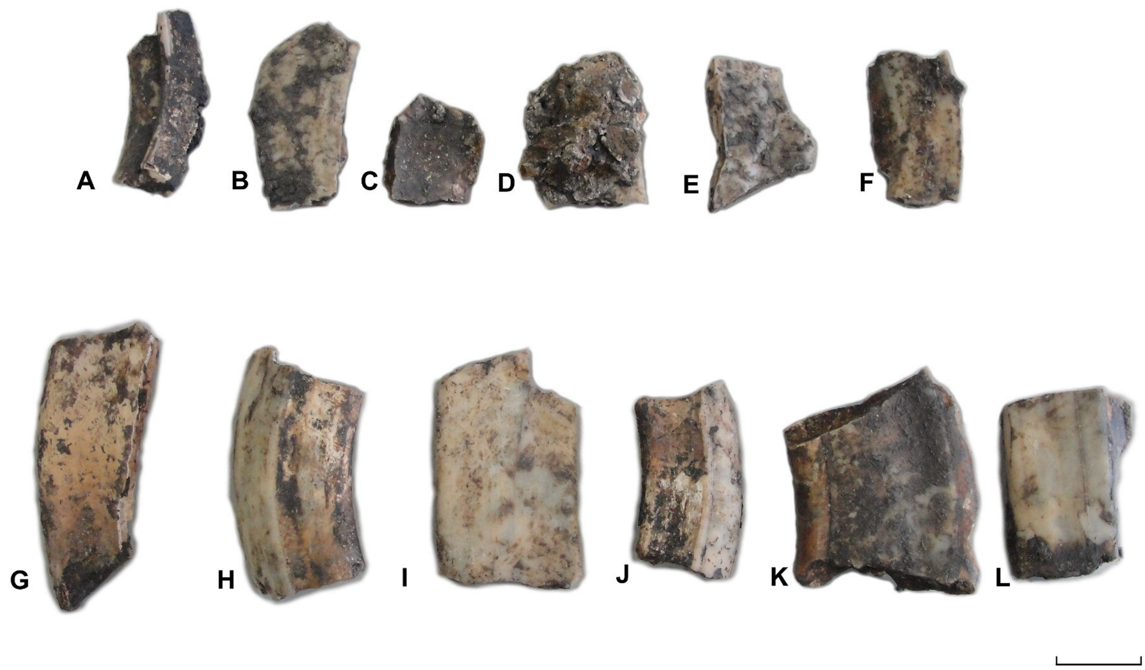

Fig. 2. Photography of teeth of *Toxodon platensis* dated in this study (scale bar: 1 cm).

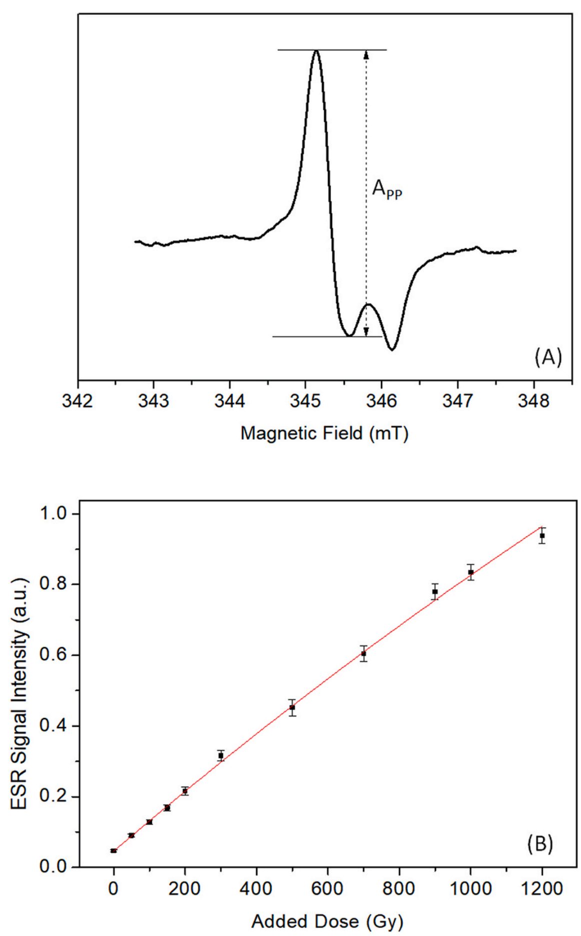

Fig. 3. (A) ESR spectrum of specimen 1 irradiated with a dose of 500 Gy, demonstrating the peak-to-peak amplitude of ESR spectrum at $g_{\perp}$. (B) Dose response curve of specimen 1.

through NAA are in Table 1.

Table 2 shows the results of dating calculated for three models of Uranium uptake: Early Uptake (EU), Linear Uptake (LU) and Combined Uptake (CU). The EU provides the minimum dating of sample, assuming that the uranium present in enamel was absorbed soon after tooth burial (Bischoff and Rosenbauer, 1981). The LU model considers that uranium was absorbed on the analyzed material at a constant rate (Ikeya, 1993). The CU model in this study was set as LU for enamel and EU for dentine, due to difference of porosities. These models were implemented in the ROSY Brennan et al. (1999) software for tooth dating. For better visualization, the dating results are also represented in Fig. 4.

Fig. 4 shows the datings obtained of each sample, according to the Uranium uptake model. The Combined Uptake (CU) model was defined with the Early Uptake (EU) for dentin and Linear Uptake (LU) for enamel due to differences in porosity. Usually, the dating provided by this model is adopted as being the most likely. However, considering the error associated to the results, the datings provided by the three models are the same.

4. Discussion

The results obtained in the samples from Lagoa do Rumo found in this study and in conjunction with previous results of Ribeiro et al. (2013), which obtained datings of 50 ± 10 ka, 43 ± 8 ka and 9 ± 2 ka from the samples AMEPR1, AMEPR2 and AMEPR3 from the same deposit, show the largest temporal mixing observed in a fossil assemblage from a tank. They also include the most recent dating obtained directly from a late Quaternary megafauna element of this region, demonstrating that the toxodontids survived until the beginning of the Holocene in the studied area (Ribeiro et al., 2013).

The taphonomic data previously obtained (Ribeiro, 2010, 2014) and the time-averaging observed shows that all the samples came from different individuals of *Toxodon platensis*, being possible that some samples can be from a single individual, due the to the overlap between datings of some, which demonstrate that at least some of them may be contemporary.

The precise number of individuals is unknown, due to the taphonomic signatures of the deposit. As shown in Fig. 2 we had only fragments of teeth what complicates the full identification of the specimens.

Table 1
Equivalent Dose (D_e) and concentration of radioisotopes measured in the samples.

Specimen	D_e (Gy)	Enamel			Dentine			Sediment		
		U (ppm)	Th (ppm)	K (%)	U (ppm)	Th (ppm)	K (%)	U (ppm)	Th (ppm)	K (%)
1	53 ± 2	<0.05	<0.01	<0.075	4.32 ± 0.43	<0.01	<0.075	2.08 ± 0.19	13.5 ± 0.64	0.20 ± 0.07
2	65 ± 5	0.090 ± 0.001	<0.01	<0.075	5.70 ± 0.57	<0.01	<0.075	3.50 ± 0.44	13.3 ± 1.5	0.32 ± 0.10
3	62 ± 6	<0.05	<0.01	<0.075	1.28 ± 0.13	<0.01	<0.075	2.07 ± 0.10	15.2 ± 5.5	0.70 ± 0.36
4	46 ± 6	0.062 ± 0.001	<0.01	<0.075	0.89 ± 0.09	0.3 ± 0.1	<0.075	3.63 ± 0.36	10.1 ± 0.32	0.25 ± 0.11
5	72 ± 11	<0.05	<0.01	<0.075	2.10 ± 0.21	<0.01	<0.075	3.62 ± 0.14	12.7 ± 3.9	0.21 ± 0.08
6	45 ± 7	<0.05	<0.01	<0.075	3.83 ± 0.38	<0.01	<0.075	3.51 ± 0.20	10.7 ± 0.4	0.465 ± 0.24
7	49 ± 3	<0.05	<0.01	<0.075	2.67 ± 0.27	<0.01	<0.075	2.03 ± 0.15	12.53 ± 1.7	0.16 ± 0.09
8	52 ± 2	0.196 ± 0.003	<0.01	<0.075	14.7 ± 1.5	0.72 ± 0.12	<0.075	4.73 ± 0.06	7.63 ± 0.99	<0.075
9	57 ± 4	<0.05	<0.01	<0.075	1.75 ± 0.18	<0.01	<0.075	2.51 ± 0.09	11.5 ± 1.55	0.21 ± 0.07
10	66 ± 4	<0.05	<0.01	<0.075	0.47 ± 0.05	<0.01	<0.075	2.13 ± 0.10	11 ± 0.35	<0.075
11	48 ± 3	<0.05	<0.01	<0.075	1.62 ± 0.16	<0.01	<0.075	2.61 ± 0.16	11.16 ± 1.15	0.43 ± 0.03
12	53 ± 7	<0.05	<0.01	<0.075	0.83 ± 0.08	<0.01	<0.075	1.92 ± 0.08	12.3 ± 1.83	0.36 ± 0.30

Table 2
Datings calculated according to three models of Uranium uptake: Early Uptake (EU), Linear Uptake (LU) and Combined Uptake (CU).

Specimen	Early Uptake (ka)	Linear Uptake (ka)	Combined Uptake (ka)
1	42 ± 2	43 ± 2	43 ± 2
2	44 ± 4	45 ± 4	44 ± 4
3	40 ± 9	40 ± 9	40 ± 9
4	39 ± 5	39 ± 5	39 ± 5
5	51 ± 8	51 ± 8	51 ± 8
6	34 ± 6	34 ± 6	34 ± 6
7	41 ± 4	42 ± 4	41 ± 4
8	37 ± 2	40 ± 2	38 ± 2
9	47 ± 5	48 ± 4	47 ± 4
10	60 ± 6	60 ± 6	60 ± 6
11	42 ± 3	42 ± 3	42 ± 3
12	46 ± 7	46 ± 7	46 ± 7

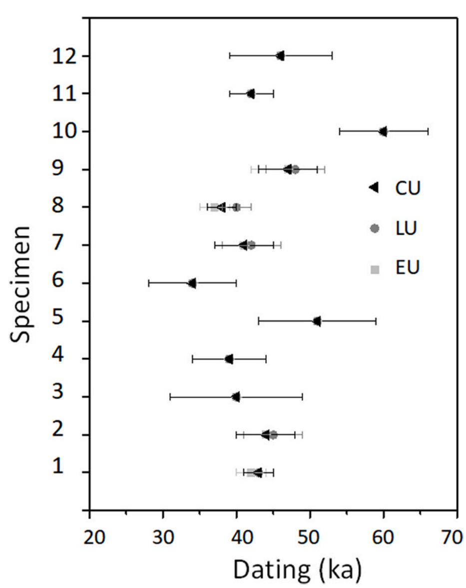

Fig. 4. Dating results according to the Uranium uptake model.

Temporal mixing in a fossil accumulation can occur due to low sedimentation rates, organisms activity (bioturbations) and reworking (Martin, 1999). The time-averaging in the Lagoa do Rumo tank, a taphonomic concept that deals with the time resolution from a fossiliferous layer (Walker and Bambach, 1971), is wider than that recorded in other Brazilian tanks (Table 3). In Puxinanã (Paraíba state), the time-averaging was approximately 5 ka (Kinoshita et al., 2005a, 2005b), while in Brejo da Madre de Deus (Pernambuco state), it was ~12.100 ka (Kinoshita et al., 2008a). In Poço Redondo (Sergipe state), the degree of temporal mixing was ~12.3 ka (Dantas et al., 2013).

The $CaCO_3$ coatings on fossils from Toca da Boa Vista and Toca das Onças caves (Bahia state) were dated by the U–Th method. The datings obtained in the Toca da Boa Vista, where most of the geochronological analyzes were carried out, indicated an even more wide temporal mixing than that found in the fossiliferous tank deposit of Lagoa do Rumo, with datings between the Middle and Late Pleistocene, ranging between 293.259 ± 9.994 ka (TBR-19 A) in $CaCO_3$ associated with an indeterminate bone, and 15.031 ± 0.375 ka (TBR-21 B) for $CaCO_3$ associated with bone of the small ground sloth *Nothrotherium maquinense* (Auler et al., 2006).

Dantas et al. (2013) presented a series of ^{14}C datings of fossils recovered from tank deposits in Vitória da Conquista and Coronel João Sá (Bahia state), Poço Redondo and Canhoba (Sergipe state); and Currais Novos, Barcelona and Rui Barbosa (Rio Grande do Norte state). Only in Poço Redondo, it was possible to infer the degree of temporal mixing of the deposit, with ~12.3 ka. Unfortunately, for the remaining deposits only a single fossil was dated and, then, interpretation about degrees of time-averaging cannot be stated from these taphocoenoses. Regarding the time interval of occurrence, we highlight the results obtained for *Toxodon platensis* fossils from Poço Redondo, 10,050 ± 30 years cal BP (UGAMS 4946), Rui Barbosa, 10,730 ± 30 years cal BP (UGAMS 4942), and Vitória da Conquista, 10,970 ± 30 yearscal BP (UGAMS 4944), which corroborate the presence of this species in the region during the Pleistocene-Holocene transition.

Holocene datings were obtained indirectly for megafauna bones in the northeastern Brazil based on analysis of sediment associated with them. In the Serra da Capivara National Park, southwest of Piauí state, sediment associated with the remains of *Palaeolama*, *Equus* and *Glyptodon*, from a cave deposit (Toca do Serrote do Artur), was dated at 8490 ± 120 years cal BP (^{14}C) (Faure et al., 1999). In another cave at the Serra da Capivara (Toca do Garrincho), sediment associated with remains radiocarbon dated as *Hippidion, Palaeolama, Pampatherium, Toxodon* and *Catonyx* was 10,020 ± 290 years cal BP (Peyre et al., 1998). In addition to these Early Holocene datings, there is a sample of sediment from the top of the fossiliferous layer of the Lagoa do Rumo dated by ^{14}C using accelerated mass spectrometry (AMS) of 8600 ± 30 years cal BP (UGAMS 5030) (Ribeiro, 2010).

The degree of temporal mixing in the fossiliferous layer of Lagoa do Rumo is ~51 ka, being considered the widest range observed in a tank deposit. The results demonstrate the presence of toxodontids at the Lagoa do Rumo region between ~66 ka until the Early Holocene at least 9 ka. These animals were adapted to environments with great availability of waterbodies, feeding on plants C3 and C4 (Dantas et al., 2013), suggesting a more humid environment than the current one in the studied area during the interval Late Pleistocene-Early Holocene, due to the inferred behavior for this taxon (Paula-Couto, 1979).

The datings obtained in ten of the analyzed teeth samples (1, 2, 3, 4, 5, 7, 9, 11 and 12) and sample AMEPR2 from the same deposit reported

Table 3
Geochronological results obtained on Quaternary vertebrate deposits of northeastern Brazil.

Site/State/Author	Deposit	Method	Dating	Taxon
Puxinanã, Paraíba (Kinoshita et al., 2005a, 2005b)	Tank deposit	ESR Tooth	30 ± 5 ka (specimen 1) 36 ± 7 ka (specimen 1, K-Band) 39 ± 7 ka (specimen 2) 39 ± 9 ka (specimen 3)	*Notiomastodon platensis* (specimen 1 and 2), *Xenorhinotherium bahiense* (specimen 3)
Brejo de Madre de Deus, Pernambuco (Kinoshita et al., 2008a)	Tank deposit	ESR Tooth	63 ± 8 ka– sample 1; 60 ± 9 ka– sample 2	*Notiomastodon platensis*
João Dourado, Bahia (Faria et al., 2020)	Tank deposit	ESR Tooth	168 ± 2.6 ka 12.5 ± 2.3 ka 9.6 ± 1 ka 9.1 ± 1 ka	*N. platensis* *N. platensis* *Toxodontinae* *Toxodontinae*
Gruta dos Brejões, Bahia (Czaplewski and Cartelle, 1998)	Cave deposit	^{14}C - Coprolite	12,200 ± 120 years cal BP NZA 6984	*Nothrotherium*
Toca do Garrincho, Piauí (Peyre et al., 1998)	Cave deposit	^{14}C Charcoal	10,020 ± 290 years cal BP GIF 9335 (minimum value, indirect ages from associated materials)	*Hippidion, Palaeolama, Pampatherium, Toxodon* and *Catonyx*
Toca do Serrote do Artur, Piauí[9] (Faure et al., 1999)	Cave deposit	^{14}C Charcoal	8490 ± 120 years cal BP GIF 10516 (minimum value, indirect ages from associated materials)	*Hoplophorus, Glyptodon, Conepatus, Panthera, Dicotyles, Tayassu, Palaeolama* and *Mazama*
Fazenda Ovo da Ema, Alagoas (Oliveira et al., 2010)	Cave deposit	ESR Tooth	10 ± 0.5 ka – AL 1 (EU); 10 ± 0.5 ka – AL 1 (LU); 39.8 ± 1 ka - AL 2 (EU); 39.8 ± 1 ka - AL 2 (LU)	*Notiomastodon platensis*
Toca da Boa Vista, Bahia (Auler et al., 2006)	Karst deposit	U–Th. $CaCO_3$ associated to bones	15,425 ± 491 a – TBR-21 A 15,031 ± 375 a – TBR-21 B 16,242 ± 293 a– TBR-22 A 16,044 ± 172 a – TBR-22 B 128,433 ± 2814 a– TBR-24 A 123,084 ± 1838 a – TBR-24 B 293,259 ± 9994 a – TBR-19 A 132,803 ± 2646 a – TBR-19 B 223,043 ± 10,911 a– TBR-25 A 222,431 ± 6840 a – TBR-25 B 15,865 ± 389 – TBV-69 B (minimum values, indirect ages from associated materials)	*Nothrotherium maquinense* (TBR-21 A and 21 B); *Mazama* (TBR-22 A and 22 B); *Puma concolor* (TBR-24 A and 24 B); Bone indet. (TBR-19 A, 19 B, 25 A and 25 B); Chiroptera (69 A and 69 B)
Toca da Onça, Bahia (Auler et al., 2006)	Karst deposit	U–Th – $CaCO_3$ associated to bones	15,000 ± 500 a - ONC-01 16,100 ± 3900 a - ONC-02 15,800 ± 2000 a - ONC-03 (minimum values, indirect ages from associated materials)	*Eremotherium laurillardi*
Poço Redondo, Sergipe (Dantas et al., 2013)	Tank deposit	^{14}C - bone	22,440 ± 50 years cal BP UGAMS 4932 10,050 ± 30 years cal BP UGAMS 4946	*Eremotherium laurillardi* (UGAMS 4932); *Toxodon platensis* (UGAMS 4946)
Canhoba, Sergipe (Dantas et al., 2013)	Tank deposit	^{14}C - bone	17,910 ± 50 years cal BP UGAMS 4939	*Notiomastodon platensis*
Currais Novos, Rio Grande do Norte (Dantas et al., 2013)	Tank deposit	^{14}C - bone	15,490 ± 40 years cal BP UGAMS 4935	*Eremotherium laurillardi*
Barcelona, Rio Grande do Norte (Dantas et al., 2013)	Tank deposit	^{14}C - bone	15,490 ± 40 years cal BP UGAMS 4935	*Notiomastodon platensis*
Rui Barbosa, Rio Grande do Norte (Dantas et al., 2013)	Tank deposit	^{14}C - bone	10,730 ± 30 years cal BP UGAMS 4942	*Toxodon platensis*
Coronel João Sá, Bahia (Dantas et al., 2013)	Tank deposit	^{14}C - bone	13,980 ± 40 years cal BP UGAMS 4938	*Notiomastodon platensis*
Vitória da Conquista, Bahia (Dantas et al., 2013)	Tank deposit	^{14}C - bone	10,970 ± 30 years cal BP UGAMS 4944	*Toxodon platensis*
Quijingue, Bahia (Drefahl, 2010)	Tank deposit	^{14}C - bone	15,770 ± 40 years cal BP UGAMS 6136	*Eremotherium laurillardi*

in Ribeiro et al. (2013) overlap in a time interval between 41 and 45 ka, indicating that these fossils could not compose a single thanathocoenosis. Due the short duration of a vertebrate thanathocoenosis (around three decades, see Behrensmeyer and Miller, 2012), the association of the fossils mentioned above with samples AMEPR3 (Ribeiro et al., 2013) and samples 6, 8 and 10 from this study can be interpreted as a temporal mixing due to the physical reworking – inside and/or outside the tank – of distinct taphocoenoses.

5. Conclusion

The results obtained by Electron Spin Resonance dating on the teeth of *Toxodon platensis* from the Lagoa do Rumo deposit revealed ages from around 60 ka to 34 ka (some 26 thousand years). Furthermore, considering the previous literature related to *Toxodon platensis* in Lagoa do Rumo, our results evidence the largest time-averaging ever recorded for tank deposits: around 51 thousand years. Despite the significant temporal mixing observed in this and other tank deposits, these numerous regional deposits, distributed in a large area of northeastern Brazil, can be considered the best source of data about the extinct megafauna of the late Quaternary, especially when it is possible to perform a satisfactory number of dating on fossils from these deposits.

CRediT author statement

Ricardo da Costa Ribeiro- Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Writing - Original Draft. **Angela Kinoshita** - Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Writing - Original Draft, Writing - Review & Editing. **Hermínio Ismael de Araújo-Júnior**- Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Supervision, Funding acquisition ,Writing - Original Draft, Writing - Review & Editing. **Ana Maria Graciano Figueiredo** Conceptualization, Methodology, Validation, Formal Analysis, Investigation. **Ismar de Souza Carvalho** -

Conceptualization, Methodology, Validation, Formal Analysis, Investigation. **Oswaldo Baffa** - Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Funding acquisition, Writing - Original Draft, Writing - Review & Editing.

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.

Acknowledgments

To FAPESP (São Paulo Research Foundation grants 2018/02866–9, 2007/06720–4, 2013/07699–0), FAPERJ (Rio de Janeiro Research Foundation grant E-26/203.176/2017) and National Council for Scientific and Technological Development (CNPq) [grants 309186/2020–0, 304107/2019–0] for financial support. Technical help from L. Rocha and C. Brunello are also appreciated.

References

Araújo-Júnior, H.I., de Oliveira Porpino, K., Ximenes, C.L., Bergqvist, L.P., 2013. Unveiling the taphonomy of elusive natural tank deposits: a study case in the Pleistocene of northeastern Brazil. Palaeogeogr. Palaeoclimatol. Palaeoecol. 378, 52–74.

Auler, A.S., Piló, L.B., Smart, P.L., Wang, X., Hoffmann, D., Richards, D.A., Edwards, R.L., Neves, W.A., Cheng, H., 2006. U-series dating and taphonomy of Quaternary vertebrates from Brazilian caves. Palaeogeogr. Palaeoclimatol. Palaeoecol. 240, 508–522.

Baffa, O., Brunetti, A., Karmann, I., Neto, C.M.D., 2000. ESR dating of a toxodon tooth from a Brazilian karstic cave. Appl. Radiat. Isot. 52, 1345–1349.

Behrensmeyer, A.K., Miller, J.H., 2012. Building links between ecology and paleontology using taphonomic studies of recent vertebrate communities. In: Louys, J. (Ed.), Paleontology in Ecology and Conservation. Springer, pp. 69–91.

Bischoff and Rosenbauer, 1981.

Brennan, B.J., Rink, W.J., Rule, E.M., Schwarcz, H.P., Prestwich, W.V., 1999. The ROSY ESR dating program. Anc. TL 17, 9.

Czaplewski, N.J., Cartelle, C., 1998. Pleistocene bats from cave deposits in Bahia, Brazil. J. Mammal. 79, 784–803.

Dantas, M.A.T., Dutra, R.P., Cherkinsky, A., Fortier, D.C., Kamino, L.H.Y., Cozzuol, M.A., de Souza Ribeiro, A., Vieira, F.S., 2013. Paleoecology and radiocarbon dating of the Pleistocene megafauna of the Brazilian intertropical region. Quat. Res. 79, 61–65.

Drefahl, M., 2010. Implicações paleoambientais preliminares da análise de δ13C em osso de paleomastofauna procedente de Quijingue, Bahia. Bol. Resumos, Simpósio Bras. Paleobotânica e Palinol. Salvador. ALPP. Bahia 239.

Faria, F.H.C., Kinoshita, A., Carvalho, I. de S., Araújo-Júnior, H.I. de, Pegorin, P., Maria G Figueiredo, A., Baffa, O., 2020. ESR dating of late Quaternary megafauna fossils from João Dourado, Bahia, Brazil. J. South Am. Earth Sci. 101 https://doi.org/10.1016/j.jsames.2020.102586.

Faure, M., Guérin, C., Parenti, F., 1999. Découverte d'une mégafaune holocène à la Toca do Serrote do Artur (aire archéologique de São Raimundo Nonato, Piauì, Brésil): a gruta do Serrote do Artur (área arqueológica de São Raimundo Nonato, Piaúi, Brasil): datações holocênicas para megafáuna de mam. Comp. Rendus l'Acad. Sci. IIA-Earth Planet. Sci. 329, 443–448.

Ikeya, M., 1993. New Applications of Electron Paramagnetic Resonance. Dating, Dosimetry and Microscopy.

Kinoshita, A., Barreto, A., Alves, R., Maria Figueiredo, A., Eduardo de Souza Sarkis, J., Dias, M.L., Baffa, O., 2008a. ESR dating of teeth from northeastern Brazilian megafauna. Radiat. Meas. 43 https://doi.org/10.1016/j.radmeas.2007.11.075.

Kinoshita, A., Figueiredo, A.M.G., Felice, G.D., Lage, M.C.S.M., Guidon, N., Baffa, O., 2008b. Electron spin resonance dating of human teeth from Toca da Santa shelter of São Raimundo Nonato, Piauí, Brazil. Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms 266, 635–639. https://doi.org/10.1016/j.nimb.2007.11.052.

C. Kinoshita, A., Magnólia Franca, A., Augusto Costa de Almeida, J., Figueiredo, A., Nicolucci, P., Graeff, O., Baffa, O., 2005a. ESR dating at K and X band of northeastern Brazilian megafauna Appl. Radiat. Isot. 62, 225–229. https://doi.org/10.1016/j.apradiso.2004.08.007.

C. Kinoshita, A., Magnólia Franca, A., Augusto Costa De Almeida, J., Maria Figueiredo, A., Nicolucci, P., Graeff, O., Baffa, O., 2005b. ESR dating at K and X band of northeastern Brazilian megafauna Appl. Radiat. Isot. 62 https://doi.org/10.1016/j.apradiso.2004.08.007.

Martin, R.E., 1999. Taphonomy: a Process Approach. Cambridge University Press.

Oliveira, L.C., Kinoshita, A., Barreto, A.M.F., Figueiredo, A.M., Silva, J.L.L., Baffa, O., 2010. ESR dating of teeth from Brazilian megafauna. In: Journal of Physics: Conference Series, p. 12062. https://doi.org/10.1088/1742-6596/249/1/012062.

Paula-Couto, C., 1979. Tratado de Paleomastozoologia. Academia Brasileira de Ciências, Rio de Janeiro, p. 590.

Peyre, E., Guérin, C., Guidon, N., Coppens, Y., 1998. Des restes humains pléistocènes dans la grotte du Garrincho, Piauí, Brésil. Comp. Rendus l'Acad. Sci. IIA-Earth Planet. Sci. 327, 355–360.

Piló, L.B., Neves, W.A., 2003. Novas datações 14C (AMS) confirmam a tese da coexistência do Homem com a megamastofauna pleistocênica na região cárstica de Lagoa Santa, MG. In: CONGRESSO BRASILEIRO DE ESPELEOLOGIA, pp. 100–104.

Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiat. Meas. 23, 497–500. https://doi.org/10.1016/1350-4487(94)90086-8.

Ribeiro, R.C., Kinoshita, A., Graciano Figueiredo, A.M., de Souza Carvalho, I., Baffa, O., 2013. Electron spin resonance dating of the late Quaternary megafauna fossils from Baixa Grande, Bahia, Brazil. Quat. Int. 317, 73–79.

Ribeiro, R.C., 2014. Assembleia fossilífera do Quaternário tardio de Lagoa do Rumo, Baixa Grande. Tafonomia e Geocronologia. Unpubl, Bahia.

Ribeiro, R.C., 2010. Aspectos tafonômicos dos fósseis da megafauna do Quaternário tardio da Lagoa do Rumo, Baixa Grande, Bahia. Unpubl. MS Diss, vol. 1. Univ. Fed. do Rio Janeiro, p. 116.

Ribeiro, R.C., 2008. Distribuição geográfica dos registros fossilíferos da megafauna do Quaternário tardio do Nordeste do Brasil. Universidade Federal do Rio de Janeiro.

Walker, K.R., Bambach, R.K., 1971. The significance of fossil assemblages from fine-grained sediments: time averaged communities. Abstracts with Programs. Geol. Soc. Am. Annual meeting, Washington, D.C, pp. 783–784.