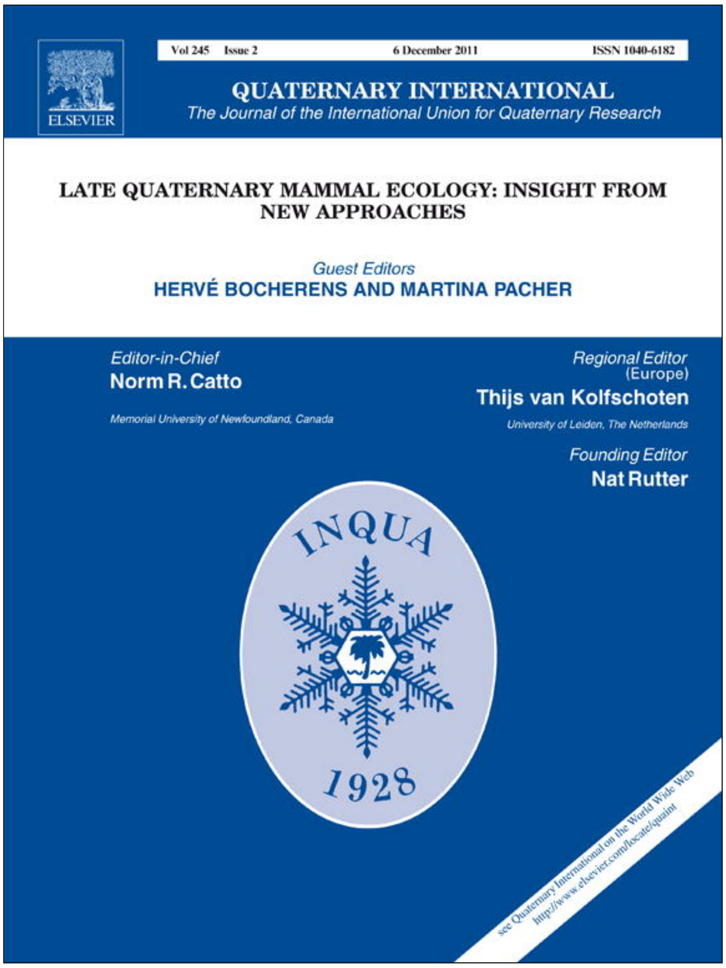
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Electron Spin Resonance dating of the southern Brazilian Pleistocene mammals from Touro Passo Formation, and remarks on the geochronology, fauna and palaeoenvironments

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A R T I C L E I N F O

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A B S T R A C T

Quaternary mammals from Touro Passo Formation (southern Brazil, Rio Grande do Sul State) were studied in the 1970s and assigned to the Pleistocene/Holocene transition, approximately between 13,000 and 3500 BP. Subsequent dating by thermoluminescence indicated that the sediments of this formation are older, between 42 and 15 ka BP, and ages obtained by AMS in mollusks and ^{14}C of charcoal ranged from 16 to 10 ka BP. However, none of these ages were obtained directly from vertebrates. In this work, four teeth samples of Artiodactyla indet., Gomphoteriidae indet. (2 samples, called G1 and G2) and *Toxodon* sp., from Ponte Velha I locality, Touro Passo Creek were dated by Electron Spin Resonance (ESR). The results are 34 ± 6 ka for Artiodactyla, 23 ± 5 ka for G1, 28 ± 3 ka for G2 and 19 ± 3 ka for *Toxodon* sp. The variation in the ages of the materials corroborates the hypothesis that the fossils of Ponte Velha I locality have been reworked. The dating contributes to the chronology of the Brazilian Pleistocene mammals and corroborates the previous interpretations on the timing of deposition of Touro Passo Formation during the late Pleistocene.

1. Introduction

The early studies on the fossil content from Touro Passo Creek (TPC) were performed during the 1970s, when Bombin (1976) described the type section of the Touro Passo Formation (TPF) in the Milton Almeida locality of this creek. This author subdivided the formation in two units, the basal conglomerate level Rudaceo Member (Membro Rudáceo) and the upper level of muddy sandstone Lamitico Member (Membro Lamítico). On basis of a ^{14}C age of 11 ka BP (Table 1) from the base of the Lamitico Member, Bombin (1976) proposed that the Rudaceo Member was deposited over the basaltic basement of the Serra Geral Formation between 13,000 and 12,000 years BP, and the Lamitico Member was deposited on top of this, between 12,000 and 3500 years BP. According to Oliveira and Lavina (2000), the members defined by Bombin (1976) characterize only a local episode of sedimentation, and more studies, considering other localities, should be made for a better understanding of the sedimentation of the Quaternary from western Rio Grande do Sul State (RS). Recently, Da-Rosa (2009) suggested that the TPF can be recognized not only in the Touro Passo Creek, but in other watercourses of Uruguay River Basin. The TPF has been temporally correlated, based on its fauna and the available radiometric dating, with Pleistocene deposits from northern Uruguay and Argentine Mesopotamian (Oliveira and Kerber, 2009).

According to Kerber (2008), in the fossiliferous localities of the Touro Passo Creek there are different sedimentary environments (point bars, floodplains, channel deposits), with different ages, sedimentology and taphonomic features, and studies of each locality are necessary, with radiometric dating to understand the evolution of this fluvial system and its palaeofauna. Although one of the best studied formations from Quaternary of southern Brazil (Ribeiro and Scherer, 2009), the TPF has few radiometric dates (Table 1). Bombin (1976) dated wood and tried to perform an

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Table 1
Previous radiometric dating of Touro Passo Creek, TPF. ^{14}C: Carbon 14, TL: Thermoluminescence, AMS: Accelerator Mass Spectrometry.

Dating	Method	Sample	Reference
11,010 ± 190	^{14}C	wood	Bombin (1976)
10,810 ± 275	^{14}C	chacoal	Miller (1987) [a]
42,600	TL	sediment	Milder (2000); Da-Rosa (2003)
15,400	TL	sediment	Milder (2000); Da-Rosa (2003)
16,327	TL	sediment	Milder (2000); Da-Rosa (2003)
15,970 ± 90	AMS	mollusk	Kotzian et al. (2005)
16,650 ± 203	AMS	mollusk	Kotzian et al. (2005)

[a] Kerber and Oliveira (2008a) referred wrongly two ages from the work of Miller (1987). These ages are from archaeological sites in Quaraí and Ibicuí Rivers.

^{14}C analysis of a fossil mammal, unsuccessfully due to the absence of collagen. This author did not mention the exact origin of the dated sample. Later published dating, using ^{14}C (charcoal), Thermoluminescence (TL) (sediments) and Acceleration Mass Spectrometry (AMS) (mollusks), showed some older ages (Miller, 1987; Milder, 2000; Da-Rosa, 2003; Kotzian et al., 2005) (Table 1). However, none of these dates were done directly on vertebrates from these sedimentary packages.

Electron Spin Resonance (ESR), also known as Electron Paramagnetic Resonance (EPR), is an important technique for analyzing the structure of the matter. This method has been successfully employed to date fossil teeth samples from Pleistocene mammals. In Brazil, Pleistocene mammals from deposits of "cacimbas", (Kinoshita et al., 2005, 2008), deposits of karst systems (Baffa et al., 2000), bones from Sambaquis (Mascarenhas et al., 1982) and recently teeth from submerged deposits and fluvial systems (Lopes et al., 2010) were dated by ESR.

The main goals of this paper are: a) to report the first absolute dating of fossil vertebrates from Touro Passo Creek, using the methodology of Electron Spin Resonance and b) provide an update on the chronology, biostratigraphy, fauna and palaeoenvironmental information of the Touro Passo Creek.

2. Location and geological setting

The materials studied in this work were collected at the Ponte Velha I locality Touro Passo Creek (29° 40 S and 56° 51 W), in Uruguaiana municipality, western Rio Grande do Sul State (RS), southern Brazil (Fig. 1A). In the Touro Passo Creek, there are several fossiliferous outcrops assigned to the late Pleistocene, Lujanian Age (*Equus neogaeus* Biozone, *sensu* Cione and Tonni, 2005), and the best studied are Milton Almeida, Ponte Velha I (Fig. 1B) and II, Barranca Grande and Confluência do Pindaí (Kerber and Oliveira, 2008a). The fossil remains are usually disarticulated, reworked, and exhibit diagenetic alterations (Kerber, 2008). The outcrops of Touro Passo Creek have abundant carbonate concretions, freshwater mollusks (Table 2), coalified woods, silicophytoliths and Pleistocene mammals (Table 3) (Kerber and Oliveira, 2008a; Bombin, 1976). The fossiliferous levels were deposited by a meandering river system in flood plains, represented by silt and clay with carbonate concretions at the top, and point bars by basal conglomerates and sandstone, deposited over the Cretaceous basalts of the Serra Geral Formation (Bombin, 1976; Da-Rosa, 2003; Oliveira and Kerber, 2009). The Ponte Velha I locality (29° 39′ 56″ S; 56° 52′ 14″ W) is one of the most fossiliferous localities of Touro Passo Creek. The fossils were collected from a bed of relatively fine conglomerates and sandstone (Fig. 1B).

3. Material and methods

Four teeth of mammals (Artiodactyla indet. - cf. Camelidae, Gomphoteriidae indet., two samples, called G1 and G2, and *Toxodon* sp.) and 100 mg of sediment were collected in the Ponte Velha I locality, Touro Passo Creek. These samples were analyzed in the Departamento de Física e Matemática of Universidade de São Paulo (FFCLRP-USP) and Instituto de Pesquisas Nucleares of Universidade de São Paulo (IPEN-SP).

Tooth enamel was mechanically separated from dentin and chemically treated with a 30% weight concentration of NaOH solution in an ultrasound bath to clean off remaining dentin. After about 60 min, samples were etched with an acidic solution (HCl 1:10) and an external layer of ~ 500 μm was eliminated. The enamel was powdered into fine particles ($\phi < 0.5$ mm) using an agate mortar and pestle, divided in aliquots (~100 mg) and a set of additive doses was given. These samples were irradiated with gamma rays, using a Gammacell Cobalt-60 irradiator at Instituto de Pesquisas Energéticas e Nucleares (IPEN) in air, at room temperature with a dose rate of 2.49 kGy/h using a 0.4 g/mm^2 thick Lucite built-up cap over the samples.

ESR spectra of samples were recorded using a JEOL FA200 X spectrometer operating at X-Band (ν ~9 GHz). The peak to peak signal amplitude at $g_\perp$ was used to construct the dose-response curve and equivalent dose (D_e) determination. Other measuring conditions were: modulation amplitude 0.2 mT, scan range 10 mT, scan time 1 min, incident microwave power 2 mW.

The concentration of ^{238}U and ^{232}Th present in the samples (enamel and dentine) and in the soil were obtained by Neutron Activation Analysis (NAA). The Potassium concentration was obtained by Atomic Absorption Spectroscopy (AAS). These data were employed to calculate the internal and external dose rates, converting D_e into age, using the ROSY software (Brennan et al., 1999).

For taphonomic inferences, specimens from the fossiliferous level of Ponte Velha I deposited in the palaeovertebrate collection of Pontifícia Universidade Católica do Rio Grande do Sul, Uruguaiana (MCPU-PV) were examined. These specimens were collected between 2006 and 2008 following taphonomic recommendations (Holz and Barberena, 1989). The following specimens were analyzed: osteoderm of *Propraopus* (MCPU-PV 230), osteoderms of pampatheriids (MCPU-PV 080; MCPU-PV 157, MCPU-PV 036), isolated osteoterms of Glyptodontidae and Pilosa (MCPU-PV 158, MCPU-PV 056, MCPU-PV 101, MCPU-PV 057, MCPU-PV 224, MCPU-PV 225, MCPU-PV 228), M1 and P4 of *Toxodon* sp. (MCPU-PV 040, MCPU-PV 041), dental fragments of Gomphoteriidae (MCPU-PV 159; 042); skull fragments of artiodactyls (MCPU-PV 059, MCPU-PV 139), fragments of chelonians (MCPU-PV 227, MCPU-PV 127), and indeterminate fragments (MCPU-PV 200). The biostratigraphic scheme follows Cione and Tonni (2005).

Detailed descriptions and systematics of the freshwater mollusks of TPF are in Oliveira and Milder (1990), Oliveira (1996b) and Santos (1997) (Table 2) and the vertebrates are in Oliveira (1992, 1996a), Oliveira et al. (1999), Oliveira and Pereira (2009), Scherer et al. (2007, 2009), Hsiou (2007, 2009), Pitana and Ribeiro (2007), Kerber and Oliveira (2008a, 2008b), Gasparini et al. (2009), and Ribeiro and Scherer (2009) (Table 3).

4. Results and discussion

4.1. ESR dating

The ESR spectra of these samples show a signal related to CO_2^- radicals created by the natural radiation in Hydroxyapatite (Callens et al., 1989, 2002), with spectroscopic factors $g_\perp = 2.0025$ and $g_{//} = 1.9973$. Fig. 2 shows the spectrum of *Toxodon* sp. enamel tooth and some irradiated aliquots. The experimental data of signal amplitude peak to peak at $g_\perp$ ($g = 2.0025$) was fitted using a saturating exponential function (1) for D_e determination. The results are listed in Table 4.

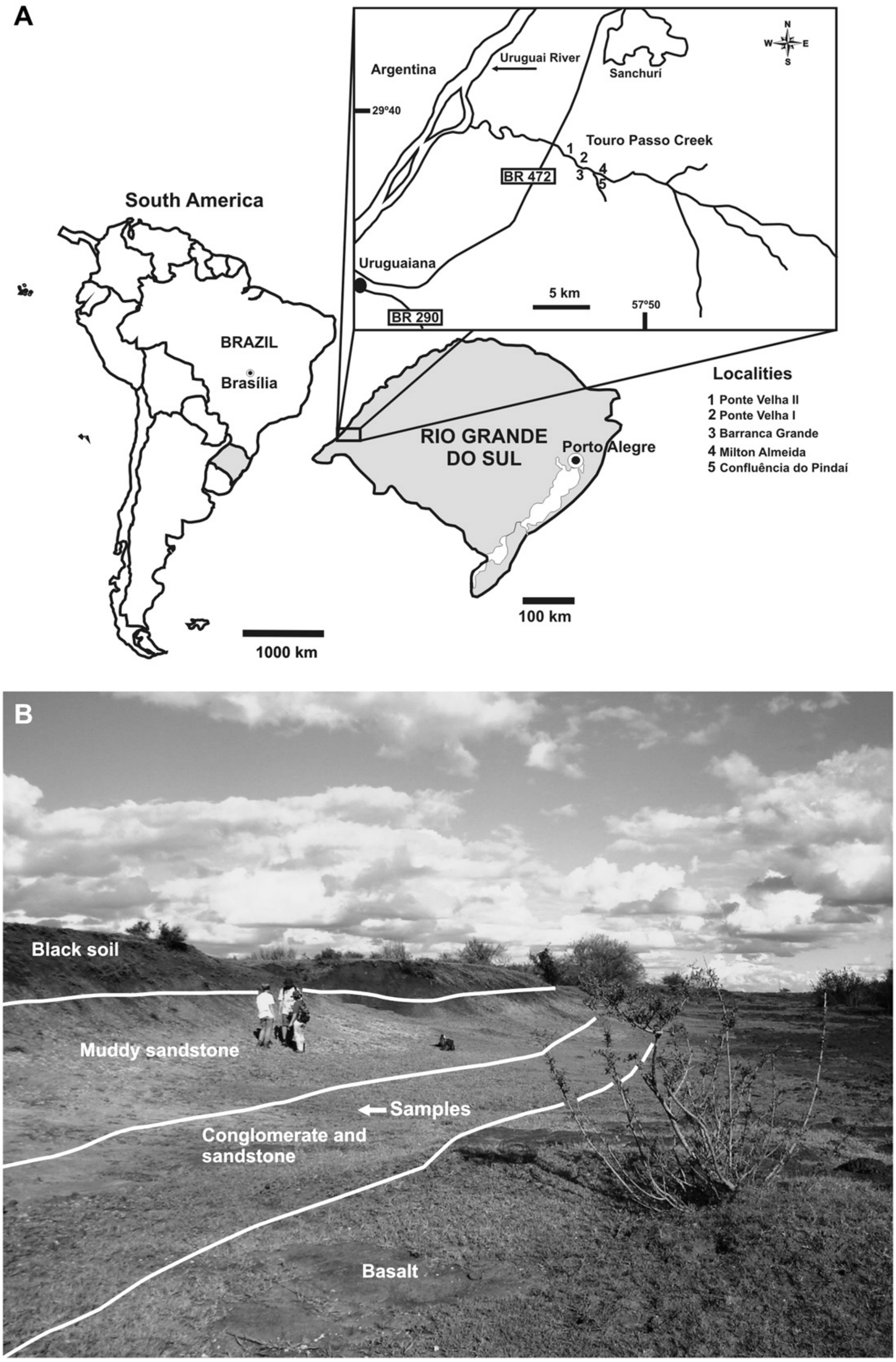

Fig. 1. A. Geographic location of Touro Passo Creek and its fossiliferous outcrops; B. Ponte Velha I locality in the Touro Passo Creek and the lithofacies exposed. Photo B by Carolina S. Scherer.

Table 2
Systematics of freshwater mollusks from Touro Passo Creek. Based on Bombin (1976), Oliveira and Milder (1990), Oliveira (1996b) and Santos (1997).

Gastropoda
Order Mesogastropoda
Family Hydrobiidae
Heleobia australis (D'Orbigny, 1835)
Heleobia parchapii (D'Orbigny, 1835)
Heleobia piscium (D'Orbigny, 1835)
Heleobia sp. Stimpson, 1865
Potamolithus lapidum (D'Orbigny, 1835)
Potamolithus petitianus (D'Orbigny, 1835)
Potamolithus sp. Pilsbry and Rush, 1896
Family Ancelydae
Gundlachia sp. Pfeiffer, 1849

Bivalvia
Order Verenoidea
Family Corbiculidae
Neocorbicula sp. Mühlfeld, 1811
Neocorbicula limosa (Maton, 1811)
Order Uniodoidea
Family Hyriidae
Diplodon aff. *piceus* (Lea, 1860)
Diplodon parallelopipedon (Lea, 1834)
Diplodon delodontus wymani (Lea, 1860)
Diplodon sp. Spix, 1827
Family Mycetopodidae
Leila blainvilleana (Lea, 1834)
Monocondylaea minuana (d'Orbigny, 1835)
Anodontites sp. Bruguière, 1792

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

I is the ESR signal intensity, D the added dose, I_0 and D_0 the intensity and the dose, respectively, at saturation. The software Microcal Origin 8.0 (Microcal Software Inc, Northampton, MA, USA) was used. Fig. 3 shows the dose dose-response curve of Artiodactyla and Gomphotheriidae 1.

Table 5 reports the concentration of radioisotopes in the samples and soil, used to convert the D_e into age. The energy released by α particles by the soil was not considered because the maximum penetration depths of these particles are 40–60 μm, shorter than the layer extracted in the sample preparation. An initial $^{234}U/^{238}U$ ratio of 1.2 ± 0.2 was assumed for age calculations. Table 4 shows the equivalent dose and the ages given by ROSY dating program according to the radioisotopes uptake model Early Uptake (EU), Linear Uptake (LU) and Combination Uptake (CU) taking into account the value of 190 μGy/y, obtained performing corrections suggested by Prescott and Hutton (1994) for latitude, longitude and depth where the samples were found. The DATA program (Grun, 2009) was also employed and the results are similar to the ROSY for EU and LU models, considering the uncertainties of D_e, radioisotopes concentrations and the depth of sample localization. This software does not present the CU option.

The CU model considered in this work used the LU for enamel and EU for dentine, due to density differences of these tissues. The dentine is porous and uranium absorption is assumed to have occurred rapidly while enamel is more compact, so the absorption occurred at a constant rate. Thus the CU model seems to represent more closely the radionuclide uptake in the teeth and, ages given by this model are more appropriate for the studied samples.

4.2. Biostratinomic features of the fossil vertebrates from Ponte Velha I locality

To characterize the fossil assemblage where the samples for dating were collected, a brief taphonomic analysis of the fossils

Table 3
Systematics of vertebrates from Touro Passo Creek. Based on Oliveira (1992, 1996a), Oliveira et al. (1999), Scherer et al. (2007, 2009), Hsiou (2007, 2009), Pitana and Ribeiro (2007), Kerber and Oliveira (2008a; 2008b), Gasparini et al. (2009), Oliveira and Pereira (2009), Ribeiro and Scherer (2009).

Reptilia
Family Teiidae
Tupinambis uruguaianensis Hsiou, 2007
Family Chelidae
Hydromedusa tectifera Cope, 1869

Aves
Family Ciconidae
Mycteria cf. *M. americana* Linnaeus, 1758
Mammalia
Xenarthra
Family Dasypodidae
Propraopus grandis Ameghino, 1881
Propraopus aff. *sulcatus* (Lund, 1842)
Propraopus sp. Ameghino, 1881
Family Pampatheriidae
Pampatherium typum Gervais and Ameghino, 1880
Holmesina paulacoutoi Cartelle and Bohorquez, 1985
Family Glyptodontidae
"*Neothoracophorus* aff. *elevatus*" Nodot, 1857
Glyptodon clavipes Owen, 1839
Glyptodon reticulatus Owen, 1845
Panochthus tuberculatus (Owen, 1845)
Panochthus sp. Burmeister, 1866
Family Mylodontidae
Glossotherium sp. (Owen, 1842)
Family Megatheridae
Megatheridae indet.
Order Notungulata
Family Toxodontidae

Toxodon sp. Owen, 1837
Order Litopterna
Family Macraucheniidae
Macrauchenia patachonica Owen, 1838

Order Proboscidea
Proboscidea indet.
Order Perissodactyla
Family Equidae
Equus (Amerhippus) neogaeus Lund, 1840
Hippidion sp. Owen, 1869
Family Tapiridae
Tapirus sp. Brünnich, 1772

Order Artiodactyla
Family Tayassuidae
Tayassu sp. Fischer, 1814
Catagonus stenocephalus Lund in Reinhardt, 1880
Family Cervidae

Antifer sp. Ameghino, 1889
Morenelaphus sp. Carette, 1922
Family Camelidae

Hemiauchenia paradoxa Gervais and Ameghino (1880)
Lama guanicoe (Muller, 1776)
Lama gracilis (Gervais and Ameghino, 1880)
Order Carnivora
Family Canidae
Canidae indet.

Order Rodentia
Family Myocastoridae
Myocastor sp. Kerr, 1792
Family Caviidae
Galea sp. Meyen, 1831
Family Hydrochoeridae
Hydrochoerus hydrochaeris (Linnaeus, 1766)
Family Cricetidae
Cricetidae indet.

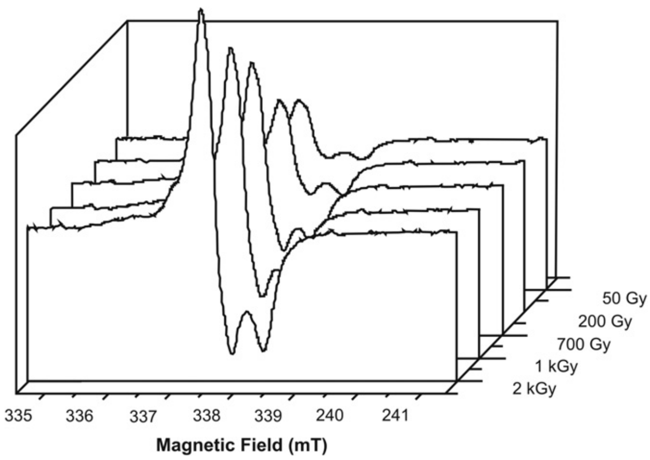

Fig. 2. ESR spectrum of tooth enamel of Gomphotheriidae 1 with different doses. The spectrum shows the signal due to the CO_2^- radical. Signal amplitude at $g_\perp$ was used to determine the D_e.

Table 4
Equivalent Dose (D_e) and age results according to the Uranium uptake model: Early Uptake (EU), Linear Uptake (LU) and Combination Uptake (CU).

SAMPLE	D_e (Gy)	EU (ka)	LU (ka)	CU (ka)
Artiodactyla	300 ± 60	20 ± 3	36 ± 6	34 ± 6
Toxodon sp.	19 ± 3	18 ± 3	21 ± 4	19 ± 3
Gomphotheriidae 1	150 ± 40	12 ± 3	23 ± 5	23 ± 5
Gomphotheriidae 2	89 ± 7	23 ± 3	39 ± 4	28 ± 3

collected in the bed of conglomerate and sandstone from Ponte Velha locality (Fig. 4) was performed. In the upper level, we do not found fossils. In this study, 291 bone elements were analyzed. The fossil assemblage of this locality showed a polytypic composition, in which several taxonomic groups are present (see Kerber and Oliveira, 2008a). Of the 291 bone elements, only 38 received taxonomic assignment (see Kerber and Oliveira, 2008a; Kerber, 2008) due to fragmentation. Almost all specimens examined are isolated and/or fragmented. The samples were grouped into size classes and a predominance of elements of small size was observed (Fig. 5). The large number of fragments and small bony elements (Group I of Voorhies, 1969) can be interpreted as evidence of intense transport in the period preceding the final burial of the bioclasts.

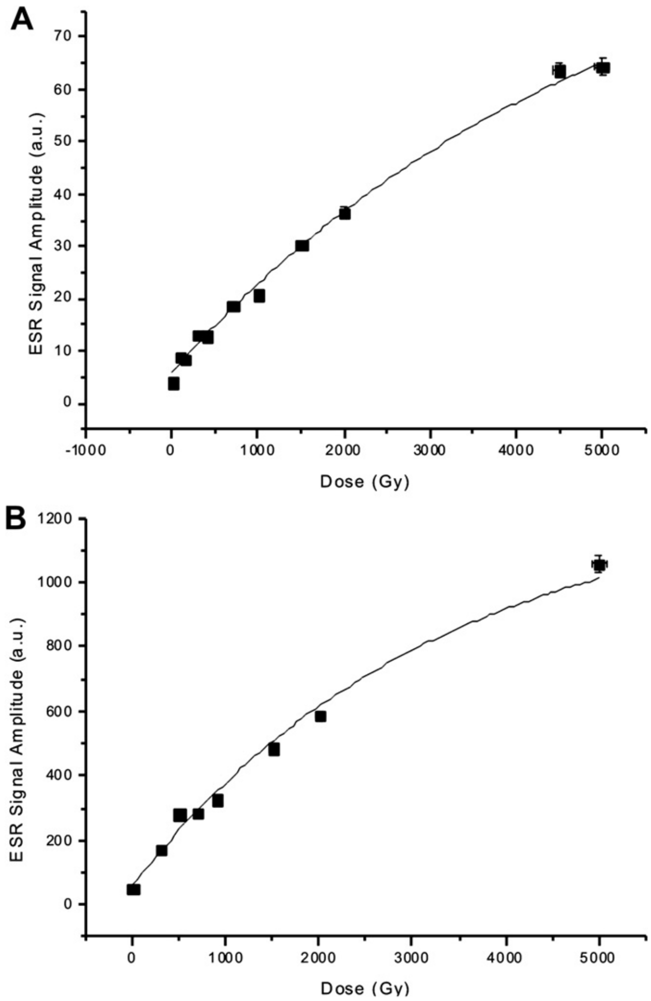

Fig. 3. Dose-response curves of Artiodactyla (A) and Gomphotheriidae 1 (B) samples. The values of D_e are (300 ± 60) Gy and (150 ± 40) obtained by exponential fitting (Eq. (1)).

Table 5
Radioisotopes concentration in enamel, dentine and soil. The average and standard deviation of values of soil was considered to age calculation.

Sample	Uranium (ppm)	Thorium (ppm)	Potassium (%)
Enamel			
Artiodactyla	87 ± 7	*<0.01	ND
Toxodon sp.	1.3 ± 0.3	<0.01	ND
Gomphotheriidae 1 (G1)	73 ± 6	*<0.01	ND
Gomphotheriidae 2 (G2)	7.7 ± 2.0	*<0.01	ND
Dentine			
Artiodactyla	160 ± 40	1.19 ± 0.02	ND
Toxodon sp.	20 ± 2	*<0.01	ND
Gomphotheriidae 1 (G1)	290 ± 70	*<0.01	ND
Gomphotheriidae 2 (G2)	209 ± 16	*<0.01	ND
Soil			
Sample 1	1.6 ± 0,4	5.8 ± 0.1	0.17
Sample 2	1.7 ± 0,1	4.9 ± 0.3	
Sample 3	1.4 ± 0,3	4.78 ± 0.09	

The fractures of the fossils analyzed have smooth and uniform surfaces, indicating that they occurred after fossilization (Fig. 6). The majority of the specimens shows abrasive wear (Fig. 6). Usually, the abrasion on the bones surface is present in elements that were prefossilized and have been reworked by erosional episodes. Thus, the elements lose their original elasticity, increase their density and are transported in the deeper area of the channel (Behrensmeyer, 1990). When bones are not fossilized, they are resistant to fragmentation and abrasion due to the elasticity of the material and are less dense and capable of floating (Holz and Simões, 2002).

The features of the fossils from Ponte Velha I indicate an accumulation of elements quite transported and concentrated. Small bioclasts of similar size, showing fragmentation and abrasion, indicate selective hydraulic transport, in an environment of high energy. According to Holz and Simões (2002), the bioclasts tend to exhibit hydraulic behavior similar to the clasts and sediment, and with the increasing distance from the area of death of the organism the skeletal elements decrease in size and are abraded and fragmented, while elements closer to this area are larger and more complete. The process of reworking and redeposition causes time-averaging, and in this case, in the same fossil assemblage, it is possible there are taxa that lived in different times (Simões and Holz, 2004). Time-averaging in TPC is also reported by Kotzian and Simões (2006) in an analysis of mollusks.

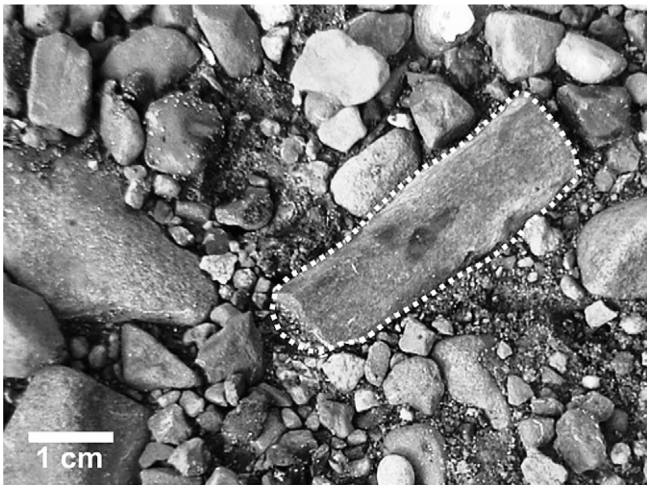

Fig. 4. Fragmented bone (outlined) among the gravels of the Conglomerate level of the Ponte Velha I locality. Photo by Carolina S. Scherer.

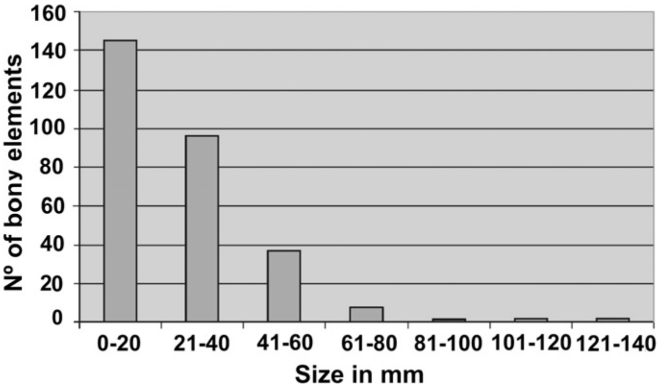

Fig. 5. Size of the fossils from Ponte Velha I locality ($n = 291$ elements).

4.3. Geochronology of Touro Passo creek and implications of ESR data

For the first time the mammals of Touro Passo Creek were directly dated using ESR. These dating ranged from 34 to 19 ka BP and they are within the variation of the previous dating by other methods (Table 1). The variation of the dating of the fossils collected in the same level supports the interpretation that the fossil assemblage of this locality was originated by reworking of older deposits, showing at least 15 ky of time-averaging. Thus, the fossiliferous level analyzed has, at the least, the age of the younger sample.

In the assemblages from TPC there are some biostratigraphic markers of the Lujanian Age, which is consistent with the ages here reported. In these outcrops, the fossils of *Equus* (*A.*) *neogaeus* are relatively common. This taxon has been considered the best guide fossil of this period, due to its wide geographical distribution during the late Pleistocene. Another taxon exclusively of Lujanian found in TPC is *Glyptodon reticulatus*.

Other Pleistocene localities with fossil vertebrates and radiometric dating from RS are also attributed to the late Pleistocene, with the exception of the submerged deposits of coastal plain that range from 600 to 20 ka BP (Lopes et al., 2010). The Sanga da Cruz locality was dated, by ^{14}C (*Glossotherium* skull) (12,770 ± 220 BP) and TL (sediments) (11,740 ± 600, 13,880 ± 800, 14,830 ± 750 years BP) (Miller, 1987; Milder, 2000). Fossil teeth from the Chuí Creek were dated by Lopes et al. (2010) using ESR, resulting in ages of 33,500 ± 8000 to 42,000 ± 3000 years BP. Sediments from the Quaraí River, on the Brazilian side were dated by TL between 13 and 11 ka BP (Ribeiro et al., 2008), and charcoal by ^{14}C between 33 and 10 ka BP (Miller, 1987).

4.4. Palaeofauna of Touro Passo Creek, palaeoenvironments and palaeozoogeography

The fossil assemblages of Touro Passo Creek have freshwater mollusks (Table 2), mammals, lizards, chelonians and birds (Table 3). The systematics of the freshwater mollusks were studied by Bombin (1976), Oliveira and Milder (1990), Oliveira (1996b), and Santos (1997), but unfortunately the first author does not refer the studied material and the diagnostic characters of the taxa. In these works, the authors suggest a faunal similarity with the Sopas Formation, with exception of *Potamolithus petitianus, Monocondylaea minuana, Diplodon aff. piceus* and *Leila blainvilleana* present only in Touro Passo Creek, and *D. paraeformis* and *D. charruanus* exclusively from Sopas Formation. According to Santos (1997), these differences may be due to failures in the knowledge on the fossil record, or less probably to the regional differences. A fact registered by Bombin (1976) and Santos (1997) is that the fossils of living taxa are larger, in size and thickness, than the modern organisms. Bombin (1976) interpreted this fact due to an "*optimum ecological*" during the time deposition of the TPF. Palaeoenvironmental changes indicated by freshwater mollusks during the deposition of these sedimentary packages were also recorded by Retamoso et al. (2001).

The last representatives of the megafauna from southern Brazil are in these deposits. The xenarthrans are represented by *Glyptodon clavipes*, *G. reticulatus*, *Panochthus* cf. *tuberculatus*, "*Neothoracophorus* aff. *elevatus*", Megatheriidae indet. *Glossotherium* sp., *Pampatherium typum*, *Propraopus grandis*, *Holmesina paulacoutoi*, and recently *Propraopus* aff. *sulcatus* was reported (Oliveira and Pereira, 2009). The large xenarthrans have been associated with open areas, with sparse vegetation (Scillato-Yané et al., 1995). The notoungulates are represented by the toxodontid *Toxodon* sp. and the litopterns by *Macrauchenia patachonica*. The artiodactyls are the cervids *Morenelaphus* sp. and *Antifer* sp., the camelids *Hemiauchenia paradoxa*, *Lama gracilis* and *Lama guanicoe*, and the tayassuids *Tayassu* sp. and *Catagonus stenocephalus*. The camelids and *C. stenocephalus* are considered indicative of drier environments than today, due to their currently distribution (Scherer et al., 2007; Gasparini et al., 2009). The camelids are restricted to the Andean Region, and *Catagonus* lives in the Chaco. On the other hand, *Tayassu* lives today in forest areas. The perissodactyls equids *Equus neogaeus* and *Hippidion principale* are indicative of open areas and the tapirid *Tapirus* sp. today lives in forest areas, with permanent water bodies. The rodents are represented by the Cricetidae aff. *Reithrodon auritus*, the myocastorine *Myocastor* sp., the hydrochoerid *Hydrochoerus hydrochaeris*, a Caviidae indet. and the caviid *Galea* (pers. obs of L K). The capybara *H. hydrochaeris* and the coypo *Myocastor* are associated with wet environments and permanent

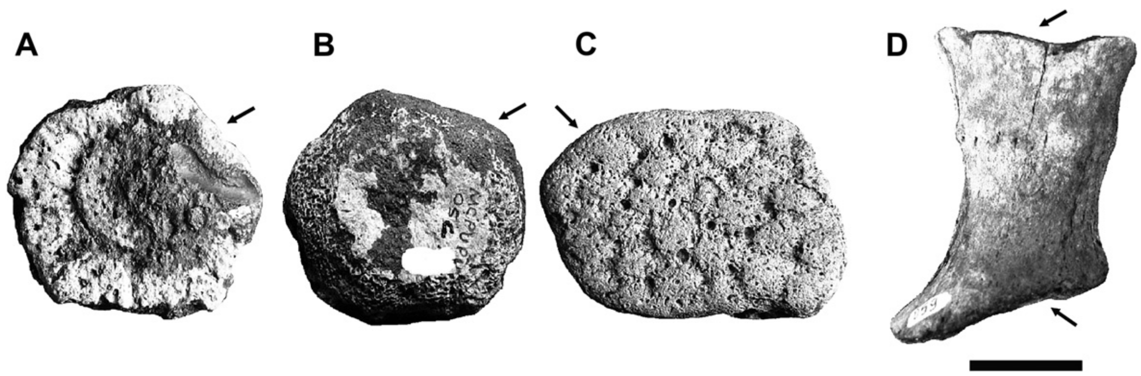

Fig. 6. Fossils from Ponte Velha I locality showing abrasive wear (indicated by arrows). A. Glyptodonts: *Glyptodon* sp., in dorsal view; B. *Glyptodon* sp., in ventral view; C. *Panochthus* sp., in dorsal view; *D. Morenelaphus* sp., in lateral view. Scale bar = 20 mm.

water bodies, and *Galea* is related to open areas. The knowledge on the Carnivora is quite scarce. The only evidence of this group are a fragmented molariform assigned as a Canidae indet and a coprolite attributed to Carnivora indet. (Kerber and Oliveira, 2008a). The birds and reptiles are poorly studied in comparison with the mammals. The Squamata are represented by a local species, the *Tubinambis uruguaianensis* and the Testudines by *Hydromedusa tectifera*. The only record of a bird in the Touro Passo Creek is a tarsometatarsus assigned as *Mycteria* cf. *M. americana*.

The palaeozoogeographic aspects of late Pleistocene from southern Brazil, northern Uruguay and Argentine Mesopotamian are peculiar and characterize a distinct zone from Buenos Aires Luján palaeofauna and the intertropical localities (*e.g.* Lagoa Santa and Bahia States). These regions show a mixture of pampean and intertropical taxa. These characteristics were observed by several authors (e.g. Oliveira, 1996, 1999; Carlini et al., 2003; Ubilla et al., 2004; Gasparini and Zurita, 2005; Kerber and Oliveira, 2008a; Ferrero and Noriega, 2009; Gasparini et al., 2009; Oliveira and Kerber, 2009).

Based on the fossils, Bombin (1975, 1976) studied the palaeoenvironments of late Pleistocene of RS. According to this author, the ecological indicatives of the fossil organisms suggest an environment with mosaic features with predominance of open areas associated with forest areas next to water bodies. In this environment there were pulses of variation in the predominance of types of vegetation due to the climatic oscillations of late Quaternary, but maintaining the general characteristics. The palaeoenvironmental indicatives of taxa from TPC should be interpreted with caution, due to the time time-averaging present in the deposits (see discussion above). The dating suggests that the deposits of TPC comprises at the least the span of time from 42,600 to 10,000 years BP, and in this period there were important climatic oscillations. The Last Maximum Glacial (LMG) reached its maximum in South America around 25,000 and ended nearly 16,000 years BP (see Rabassa et al., 2005), leading to the increase of temperatures during the final Pleistocene/Holocene. Around 11 ka BP in the Northern Hemisphere, a cold climatic pulse, the Younger Dryas, is registered. This event is also recorded in some localities from South America, as in Chile, between 11,400 and 10,200 years BP (Hadjas et al., 2003). In Buenos Aires Province, Tonni et al. (2003) suggested that the arid conditions of around 10 ka BP can be related to this event.

The late Pleistocene climatic oscillations may have afforded the latitudinal displacement of the palaeofauna and can be related with the presence of tropical and austral taxa in these deposits. However, these climatic alterations are not fully understood in southern Brazil, in contraposition to other regions of Brazil where different climatic intervals were recognized in this span of time (see Ledru et al., 1996 and references; Salgado-Laboriau, 2001; De Oliveira et al., 2005). The palynological data of RS suggest colder climates based in the predominance of grassland vegetation, at the least, in the period between 40,000 years BP and the early Holocene (see Bauermann et al., 2009). According to Behling (2001 and references therein), during the late Pleistocene, the grasslands dominated the southern and southeast Brazil, where today different ecosystems exists. The author estimated that the grasslands, today restricted in the southern Brazil, were displaced 750 km, from the latitudes of about 28°/27°S to at the least 20° S. Thus, further studies should be encouraged to detect these oscillations in southern Brazil, to understand the climatic and environmental evolution in this area, as well to test the hypothesis on the extinction of the megafauna in this area during the Pleistocene/Holocene transition.

5. Conclusion

For the first time, mammals from Touro Passo Formation were dated using ESR. The dating obtained by ESR, and the taphonomic analysis shows the importance of the associated study, because the results of both approaches are in agreement, revealing the time-averaging in the fossil assemblage of Ponte Velha I locality of, at the least, 15,000 years. The dating contributes to the chronology of the Brazilian Megafauna and corroborates the previous interpretations on the time of deposition of Touro Passo Formation. According to current radiometric dating, these sedimentary packages were deposited in a span of time between 42,600 and 10,000 years BP, by successive episodes of deposition and erosion during MIS 3 and 2.

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