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Procyonidae (Carnivora) in a cave in the Parque Nacional de Ubajara, Northeast of Brazil (Eoholocene)

Procyonidae (Carnivora) em uma caverna do Parque Nacional de Ubajara, Nordeste do Brasil (Eoholocene)

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Abstract: The most recent procyonids of Brazil came from North America at the end of the Pleistocene. This work presents and describes the first carnivore record (Procyonidae Gray, 1825) found in a cave deposit and collected from dated sediments in northeastern Brazil. The collection was made during an excavation mission at the Gruta do Urso Fóssil, Parque Nacional de Ubajara, State of Ceará. The studied material was found at a depth of 0.8 m. Using the Thermoluminescence and Optically Stimulated Luminescence methods, the material was dated to ± 8,450 years BP. The animal is represented by a maxilla fragment with a complete right M2 and can be attributed to *Procyon cancrivorus* (Cuvier, 1798). The presence of this species in this area suggests that the environmental dynamics of the region has been harmonious and conserved for, at least, the last 8,000 years.

Keywords: Carnivora; Holocene; Ubajara National Park, Ceará.

Resumo: Os procionídeos mais recentes do Brasil vieram da América do Norte ao final do Pleistoceno. Este trabalho apresente e descreve o primeiro registro de carnívoros (Procyonidae Gray, 1825) em um depósito de caverna, coletado em sedimentos datados no Nordeste do Brasil. A coleta realizou-se durante uma missão de escavação na Gruta do Urso Fóssil, Parque Nacional de Ubajara, Estado do Ceará, encontrando-se a uma profundidade de 0,8 m. Utilizando os métodos de termoluminescência e luminescência oticamente estimulada, o material foi fechado com uma idade de ± 8.450 anos AP. O animal está representado por um fragmento de maxila com o M2 direito completo e pode atribuir-se a *Procyon cancrivorus*. A presença desta espécie nessa zona sugere que a dinâmica ambiental da região tem sido harmoniosa e que está conservada há pelo menos 8.000 anos.

Palavras-chave: Carnivora; Holoceno; Parque Nacional de Ubajara, Ceará.

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1. Introduction

The oldest fossil record of the order Carnivora Bowdich, 1821, is a primitive carnivore from the Ravenscrag Formation, Canada, dated to the early Paleocene (JOHNSTON & FOX, 1984). In South America, the fossil record of this group appears shortly after the rise of the Isthmus of Panama, where the first placental carnivores entered the continent during the Great American Biotic Interchange (GABI).

The family Procyonidae Gray, 1825, first appears during the Upper Eocene–Upper Oligocene in western Europe (WOLSAN & LANGE-BADRÉ, 1996). This was the first group to disperse to South America (WOODBURNE et al., 2006), where they are found since the Upper Miocene (SOIBELZON & PREVOSTI, 2007; WOODBURNE, 2010; RUIZ-RAMONI et al., 2018). Procyonids may have invaded the South American continent a second time at the end of the Pleistocene, having the present-day living taxa as protagonists (PATTERSON & PASCUAL, 1968; WEBB, 1985; SOIBELZON, 2011). The first procyonids to have entered South America are represented by the extinct genera *Chapalmalania* and *Cyonasua* (RUIZ-RAMONI et al., 2018). The latter shows a much more predatory habit than present-day procyonids based on its dental morphology (SOIBELZON et al., 2010), competing with marsupials of the order *Sparassodonta* Ameghino (1894) for resources, which could have contributed to the extinction of such metatherians. Also coming from North America, the most recent procyonids differ from those of the first invasion due to their omnivorous feeding habit, which facilitated the sharing of resources with other eutherians already installed (ursids, felids, canids, etc.) and consequently provided for the success of the group. Nowadays, five genera of procyonids inhabit South America (*Bassaricyon* Allen, 1876, *Nasuella* Hollister, 1915, *Potos* Geoffroy Saint-Hilaire & Cuvier, 1795, *Nasua* Storr, 1780 and *Procyon* Storr, 1780), but only *Procyon* and *Nasua* have fossil records (SOIBELZON et al., 2010; RODRIGUEZ et al., 2013; RAMÍREZ et al., 2015; RUIZ-RAMONI et al., 2018) distributed among Argentina, Brazil and Uruguay (PAULA-COUTO, 1970; SOIBELZON et al., 2010).

The genus *Procyon* comprises three species: *P. cancrivorus* (Cuvier, 1798), *P. lotor* (Linnaeus, 1758) and *P. pygmaeus* Merriam, 1901. The presence of Quaternary-aged procyonids in Brazil is recorded only in the states of Bahia (LESSA et al, 1998), Minas Gerais (PAULA-COUTO, 1970) and Tocantins (RODRIGUEZ et al., 2013), all of which were found in speleothem environments.

During the period from 2009 to 2012, fieldwork in the karst region of the Parque Nacional de Ubajara (PNU), Northwest of the State of Ceará, enabled the collection of remains of invertebrates and small vertebrates, including fish, lizards, snakes, birds, armadillos, rodents, marsupials and carnivores (OLIVEIRA et al., 2018, 2014a, 2014b, 2013, 2011; CHAVES et al., 2018; SOUSA et al., 2017; HSIOU et al., 2012). This work is part of the paleofaunistic studies that have been systematically developed in the PNU region, presenting the first procyonid carnivore record from the Holocene in Ceará.

Geological Settings

The PNU is located in the Northwest region of the State of Ceará in an area that covers part of the Municipalities of Ubajara, Tianguá and Frecheirinha, on the slopes of the Ibiapaba glint (Figure 1). It presents a unique characteristic among the Brazilian parks: the direct transition from humid Forest, in its higher portion, to Caatinga, in its lower portion (IBAMA, 2002).

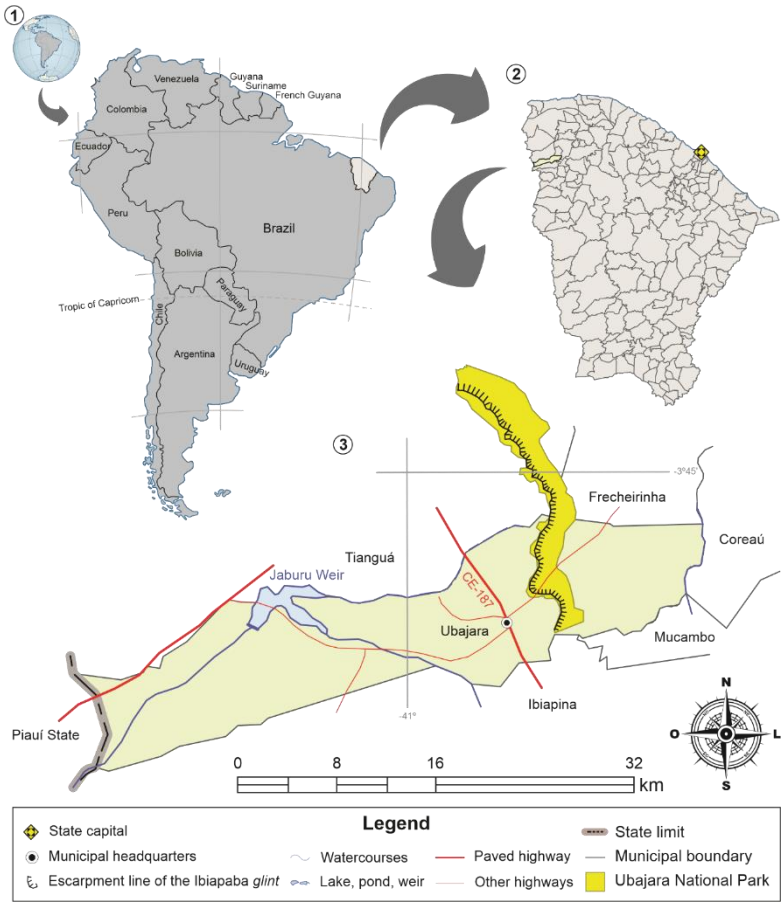

Figure 1 – Map of the State of Ceará within South America (1 and 2) with an emphasis on the municipality of Ubajara and its National Park (3), Northeast of Brazil.
Source: P. V. Oliveira (2022).

Neoproterozoic limestone (Frecheirinha Formation, Ubajara Group, Ubajara Basin) outcrops in the park area forming nine hills that make up the karst surface of the Ubajara Speleological Province. These hills shelter 14 underground cavities prone to the accumulation of recent organic remains and fossils (IBAMA, 2002; OLIVEIRA, 2010) in the so-called Quaternary cave deposits. Such deposits are characterized by their predominantly chemical origin from carbonate precipitation. Furthermore, the presence of clasts is relatively common, comprising fragments of speleothem structures and remains of organisms that inhabit the site, live in the cave, or are taken there by predators. Among these cavities, the Gruta do Urso Fóssil (GUF) (03°49'58''S/40°53'34,4''W), where the research material was found, stands out at the Pendurado Hill for its great paleontological potential (OLIVEIRA, 2010, 2014).

2. Methodology

The excavation work enabled the collection of several small bone and tooth fragments by sieving the sediments. Among them, the specimen object of this study was found in the layer 8 (excavated 0,8 m deep into the cave floor), represented by a maxilla fragment with a complete right M2. In the laboratory, the specimen was prepared using needles and brushes, removing carbonate particles that were aggregated or embedded in it. Subsequently, the tooth was wrapped in cotton and stored in an appropriate plastic container, in order to maintain its integrity, and was incorporated into the paleontology collection of the *Museu Dom José* (MDJ), in association with *Universidade Estadual Vale do Acaraú* (UVA), in Sobral-Ceará, under the record number MDJ M-1417.

The material was analyzed using a stereomicroscope and compared with living procyonid specimens that occur in the region belonging to the Mammalogy collections of the *Museu Nacional* (MN), of the *Museu de Ciências Naturais da*

Pontifícia Universidade Católica de Minas Gerais (MCL PUC/MG) and of the *Universidade Federal de Pernambuco* (UFPE), which allowed for its identification. Wilson & Reeder's (2005) systematics was followed, and the descriptions and dental terminology are in line with Paula-Couto (1979), Smith & Dodson (2003) and Koenemann et al. (2006), as well as other terms that are well established in the literature.

The following measurements were taken: overall width, length at the level of the three lingual cusps, width at the level of the labial flexion between the labial cusps, and length at the level of the labial cusps (Figure 2).

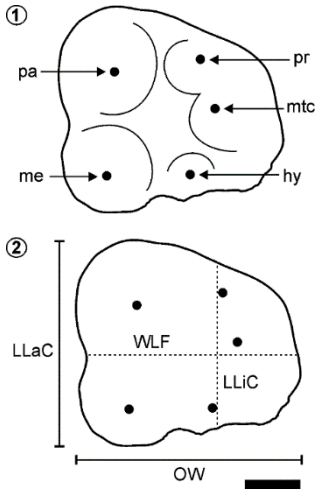

Figure 2 – Diagram showing the dental cusps on the occlusal face of the right M2 (1) and measurements taken (2). Abbreviations: pa, paracone; pr, protocone; me, metacone; hy, hypocone; mtc, metaconule; OW, overall width; LLaC, length at the level of the labial cusps; WLF, width at the level of the labial flexion between the lingual cusps; LLiC, length at the level of the three lingual cusps. Scale: 0.2 cm.
Source: P.V. Oliveira (2022).

****Anatomical abbreviations. LLiC**, length at the level of the three lingual cusps; **LLaC**, length at the level of the labial cusps; **hy**, hypocone; **WLF**, width at the level of the labial flexion; **OW**, overall width; **M2**, maxillary second molar; **me**, metacone; **mtc**, metaconule; **pa**, paracone; **pr**, protocone.
Fossil specimens used for comparison. MN 345, 1044, 3087, 3094, 4870, 4897, 5503, 5504, 5643, 7256, 7577, 7612, 11203, 23884, 23885, 23887, 25310, 25657, 25689, 25690, 28802, 32377, 32378, 32380, 32383, 32384, 32387, 69792; MCN-M (PUC/MG) 1742, 1887, 2115, 2116, 2331, 2567; UFPE 1160, 2747.

3. Results and discussion

The excavations carried out at GUF, with strict stratigraphic control, enabled the creation of the stratigraphic profile of the excavated area (Figure 3). The sedimentary package analyzed inside the cave measured approximately 90 cm and was divided into nine layers (C1-C9), each 10 cm thick. The specimen was recovered during *in loco* sieving. Only the layer 9 was consolidated. Sedimentological samples of the layers were dated by Oliveira (2014) using Thermoluminescence and Optically Stimulated Luminescence, making it possible to determine the age of the deposit as early Holocene, with ages ranging from 7,000 to 9,410 years Before Present.

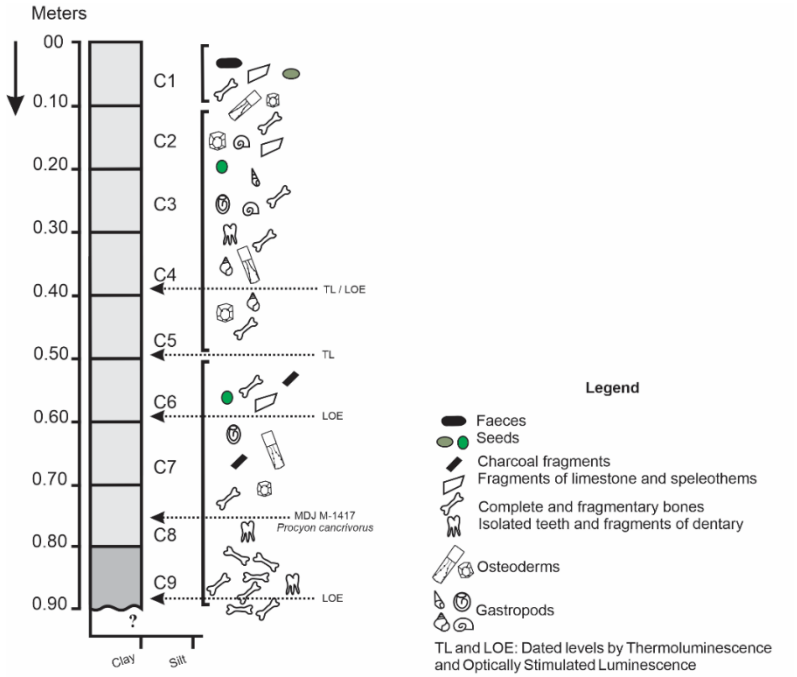

Figure 3 – Stratigraphic profile of the Entrance Room of Gruta do Urso Fóssil, showing the layers that were analyzed and dated, the representation of the collected fossil content and the origin of the studied material. Source: Modified from Oliveira et al. (2018).

*****Systematic Paleontology***

Order Carnivora Bowdich, 1821
Suborder Caniformia Kretzoi, 1945
Infraorder Arctoidea Flower, 1869
Superfamily Musteloidea
Family Procyonidae Gray, 1825
Subfamily Procyoninae
Procyon Storr, 1780
Procyon cancrivorus (Cuvier, 1798)
Figures 4A–C

****Material.** MDJ M-1417, maxilla fragment with a complete right M2.
Stratigraphic provenance. GUF, Entrance Room, layer 8 (0.8 m deep).
Morphological description and characterization. Unworn tooth, with well-developed and preserved conical cusps, except for the metaconule (partially fragmented); the paracone (mesiolabial) is the highest and most robust cusp, and is flanked by the protocone (mesiolingual); mesially near the protocone is located the paraconule, from which a ridge-like prolongation projects touching the paracone, contributing to a mesial fossa delimited by a structure similar to a mesiolabial cingulum; mesiolingually, at the base of the protocone there is a cingulum that extends distally, contributing to the hypocone formation, which is the lowest and most distal of all the cusps; the metacone is well individualized and its base contains a broad labial-distal cingulum that ends at the base of the metaconule. The lowermost area between the paracone, protocone, metacone and metaconule resembles a wide, shallow fossa.

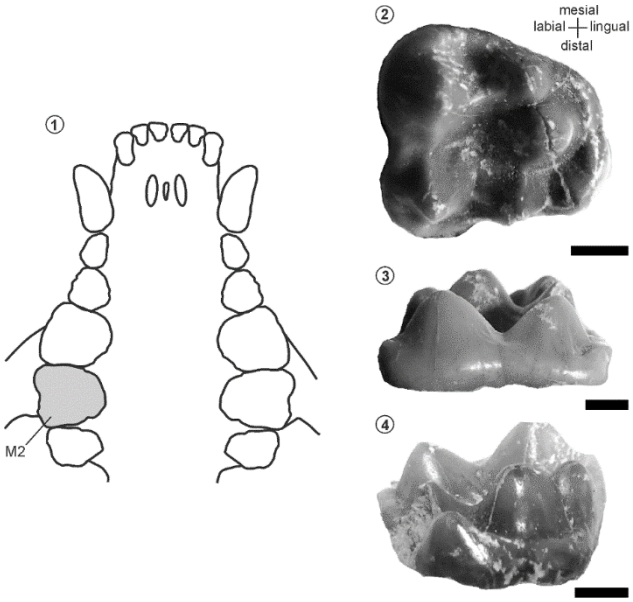

Figure 4 – Procyon cancrivorus. Schematic drawing showing the location of the studied tooth (1) and MDJ M-1417, a complete right M2 (occlusal (2), labial (3) and lingual (4) faces). Scales: 0.2 cm.
Source: P. V. Oliveira (2022).

The dental anatomy observed in MDJ M-1417 is identical to that observed in the 36 recent specimens of *Procyon cancrivorus* used for comparison. Once the specific identification was achieved by means of comparative morphoanatomical analysis of the specimen, four measurements were determined in order to verify the existence of metric variation across the specimens, and the data was used to confirm the species identification.

The total sample comprises 36 measured specimens, which had the right M2 measured (Figure 2) in millimeters (mm) using a digital caliper. The measurements are presented in the table below (Table 1), showing the similarity between the size of MDJ M-1417 compared to the other specimens measured. With these measurements, a linear regression diagram could be drawn (Figure 5). Analyzing the diagram with the measurements of the right M2 of *Procyon cancrivorus* and comparing the length-width ratio, it is observed that, in general, the specimens are located next to the adjusted regression line found for the two variables (r = 0.63), and that MDJ M-1417 is very close to the line, within the range of this correlation.

Table 1 – Right M2 measurements (mm) of 36 specimens of Procyon cancrivorus. Abbreviations: OW, overall width; LLaC, length at the level of the labial cusps; WLF, width at the level of labial flexion; LLiC, length at the level of the three lingual cusps. When n is > 1, the first line is the mean ± standard deviation, the second line is the interval and the third is the number of species measured (n).

	OW	LLaC	WLF	LLiC
Procyon cancrivorus	11,40 ± 0,61 10,12 - 12,76 (36)	10,29 ± 0,57 8,65 - 11,47 (36)	10,82 ± 0,55 9,56 - 12,20 (36)	8,96 ± 0,47 7,82 - 9,96 (35)
MDJ M-1417	11,62	10,65	10,73	9,08

Source: P.V. Oliveira (2022)

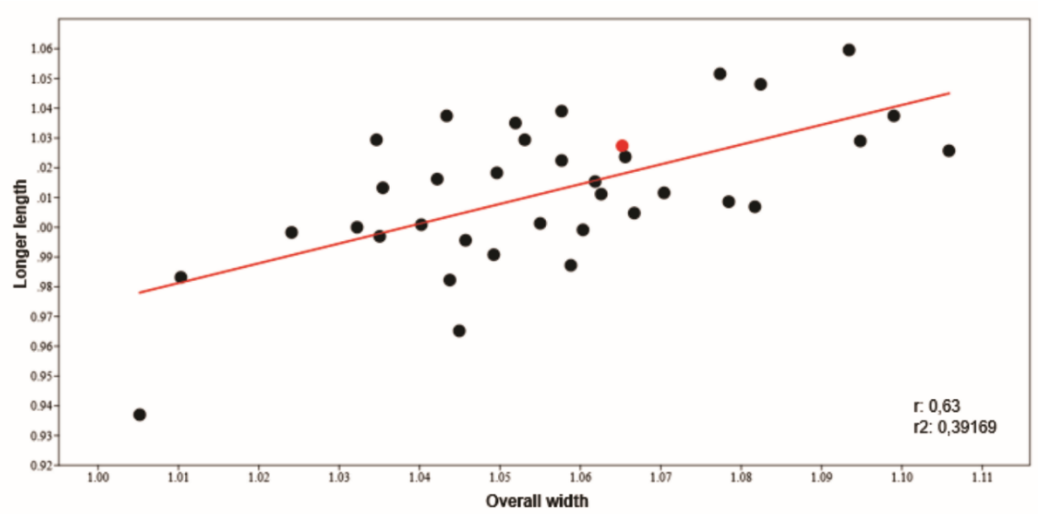

Figure 5 – Length-width linear regression of the right M2 of Procyon cancrivorus in logarithmic scale between MDJ M-1417 (in red) and the 36 specimens used for comparison.
Source: P.V. Oliveira (2022).

The genus *Procyon* comprises three species: *P. cancrivorus* (Cuvier, 1798), widely distributed across South America, and in Brazil as a whole; *P. lotor* (Linnaeus, 1758) native from Central and North America, with no occurrence in Brazil, introduced in Europe and Asia (TEIXEIRA & AMBROSIO, 2006); and *P. pygmaeus* Merriam, 1901, occurring in Cozumel Island, Mexico. Dental morphological and morphometric analyses of MDJ M-1417 showed similarities with *P. cancrivorus*, which confirms previous studies about its biogeographical distribution.

The morphology described for this specimen is the same as the one observed by Koenemann et al. (2006). MDJ M-1417 cannot be compared to UNIRIO-PM 1007 (specimen of the *Universidade Federal do Estado do Rio de Janeiro*), specimen from the Gruta do Urso, Municipality of Aurora do Tocantins, attributed to the species *Procyon cancrivorus* (see RODRIGUEZ et al., 2013), because the latter is a m2. The material from Gruta dos Brejões (MCL 1847/01, specimen of the *Museu de Ciências Naturais da Pontifícia Universidade Católica de Minas Gerais*), Municipality of Morro do Chapéu, State of Bahia, attributed to *Procyon cancrivorus* by Lessa et al. (1998), is a skull fragment missing the maxilla and right zygomatic arch, and palatines. Given the absence of the right M2, it cannot be used for comparison either. The family Procyonidae was also reported by Paula-Couto (1970), study in which the author only mentions the presence of procyonids in the material collected in the caves of the Rio das Velhas valley, region of Lagoa Santa, Minas Gerais, without further detail.

The specimens of *Procyon cancrivorus* that had the right M2 measurements taken, and that enabled the creation of the dispersion diagram, are current and from several Brazilian states: Alagoas, Ceará, Bahia, Espírito Santo, Pará, Rio de Janeiro, São Paulo, Mato Grosso e Minas Gerais, as well as 10 specimens of unknown provenance, but which also had the measurements of the right M2 taken. The fact that the specimens are from different regions shows how widely distributed the species is in Brazil, having adapted to different biomes (CHEIDA et al., 2013). Considering the measurements obtained, it is observed that there are no significant differences between the individuals from different geographical regions of the country. The statistical summary of the measurements presented here allows us to attribute the specimen MDJ M-1417 to the species *Procyon cancrivorus*, since it is within the size range found for this species, and confirms the identification resulting from the comparative analysis of the dental anatomy.

Data obtained by Oliveira (2014) show that the fossiliferous content found in the GUF's Entrance Room is composed of bone fragments of amphibians, birds, crustaceans, lizards, gastropods, fish, rodents and snakes, organisms that may be part of the diet of *P. cancrivorus*, indicating it as one of the potential contributors to the genesis of such deposit. It is noted that *P. cancrivorus* presents a wide feeding spectrum, and is classified by Quintela et al. (2014) as a frugivore-omnivore, as it feeds on fruits, invertebrates and small vertebrates. According to Einsenberg & Redford (1999), this species can be found in several habitats, such as gallery forests or the Amazonian rainforest, but always near bodies of water.

Fossils attributed to *P. cancrivorus* in Brazil are scarce and lack absolute age data, being relatively dated based on other fossils collected in the same layer and known to be from the late Pleistocene–early Holocene (*e.g.* Glyptodontids, Gonphoterids and Megatherids). Occurrences of *P. cancrivorus* are from cave deposits in the States of Bahia (Lessa et al., 1998), Mato Grosso do Sul (SALLES et al., 2006), Minas Gerais (PAULA-COUTO, 1970) and Tocantins (RODRIGUES et al., 2014). The reported material (MDJ M-1417) is the first record of this species in sediments absolutely dated (± 8,450 years BP).

The current presence of *P. cancrivorus* in the PNU area was reported in zoological studies from the early 2000s (GUEDES et al., 2000; OLIVEIRA et al., 2003). Thus, this discovery shows that this species inhabits the area for, at least, 8,450 years BP. However, because it is a taxon with wide geographic distribution (see EISENBERG & REDFORD, 1999) and a wide feeding spectrum, it cannot be used as a tool (bioindicator) to indicate potential disturbances in the environmental dynamics of the area (CHEIDA, 2013), nor to infer the occurrence of paleoenvironmental changes that could have happened since the early Holocene to the present date. Nevertheless, other studies based in taxa found in the same cave indicate that the environmental dynamics of the region shows some harmony and conservation for, at least, the last 8,000 years (OLIVEIRA, 2010, 2014; OLIVEIRA et al., 2014a, b).

4. Final considerations

The material MDJ M-1417, maxilla fragment with a complete right M2, found in the GUF's Entrance Room, was attributed to the species *Procyon cancrivorus* based on morphometric and anatomical analyses.

This material is the first dated record found in sediments in Brazil, reporting its presence in the region for at least 8,450 years BP and confirming studies that the area remains unchanged for at least 8,000 years BP. The sedimentary level was dated by Optically Stimulated Luminescence.

Nevertheless, this species cannot be used as environmental indicator due to its broad occurrence in different environments.

The presence of *Procyon cancrivorus* in sediments from the GUF's Entrance Room allows pointing it out as one of the probable agents responsible for the genesis of said deposit, since a considerable part of the taxa found in the excavated area belongs to its diet.

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