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Tooth Marks of Mammalian Incisors on Rocky Substrate in Brazil: Evidence of Geophagy in the Cerrado Biome

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Tooth marks on sandstone in an area of the Cerrado Biome are reported, indicating geophagy. The tooth marks were found on reddish sandstones cropping out in a pasture environment with typical components of the Cerrado Biome, in the Municipality of Campina Verde, Triângulo Mineiro region (west Minas Gerais State, Brazil). Studies have shown that the soil of the Cerrado is acid, with a low concentration of nutrients and minerals (also present in the plants living on this environment), which usually produce an alimentary deficiency in herbivorous animals. Therefore, these tooth marks indicate geophagy, in order to extract extra minerals from these sandstone levels, which have a high concentration of calcium carbonate and iron. The tooth marks consist of two parallel concave grooves and a medial prominent crest which results from the action of the incisors of mammals. Although the identification of the gnawing species for these sets of tooth marks are estimates at best, after wide comparisons we tentatively suggest that the tooth marks are most likely the result of the action of the incisors of rodents, such as *Dasyprocta* or *Coendou*.

Keywords Cerrado, Geophagy, Mammalia, Tooth marks, Triângulo Mineiro

INTRODUCTION

The ingestion of soil or geophagy is a regular activity of wild animals, especially those with frugivorous and herbivorous alimentary requirements (e.g., Jones and Hanson, 1985; Kreulen, 1985; Nelson Beyer et al., 1994). Several studies have demonstrated that the main benefits of geophagy include ingestion of mineral nutrients, such as sodium, calcium, magnesium, potassium, iron, and fluorine, as detoxification due to harmful components present in consumed plants or for attenuating gastrointestinal problems (Allen et al., 1986; Atwood et al., 2002; Bravo et al., 2010; Brightsmith et al., 2008; Baillie et al., 1988; Jones and Hanson, 1985; Klaus et al., 1998; Mahaney et al., 1995). Geophagy is strongly influenced by climatic, geographic, and taxonomic factors due to weather seasonality, variations in available food resources, soil pedology, and floristic components of the region, among others. The list of animals that ingest soil is large, not only includes a vast variety of mammals (e.g. Baillie and Davies, 1988; Moe, 1992; Beyer et al., 1994; Houston et al., 2001; Blake et al. 2011), but also turtles, lizards, crocodiles, and birds (Sokol, 1971; Diamond et al., 1999; Esque and Peters, 1994).

In this contribution, abundant tooth marks produced by incisors of mammals on rocky substrate are reported and analyzed, indicating soil ingestion in the Cerrado Bioma. The tooth marks were observed in a natural area in the Municipality of Campina Verde, Triângulo Mineiro region, Minas Gerais State, Brazil (Figs. 1 and 2). Based on the characteristics of the tooth marks (Figs. 3 and 4) and additional data from the environment, the mammal likely responsible for them and why geophagy is relevant in the Cerrado are issues discussed here. Although there are several studies on geophagy of neotropical South American animals (e.g., Emmons and Starck, 1979; Tobler et al., 2009; Blake et al., 2011; Link et al., 2012),

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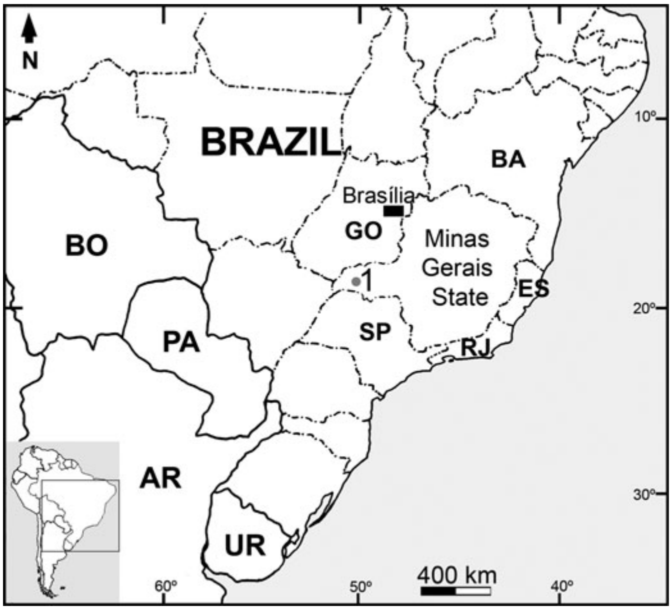

FIG. 1. Location map of the site where the tooth marks were recorded in the Municipality of Campina Verde (1), Minas Gerais State, Brazil. Abbreviations: AR: Argentina; BA: Bahia State; BO: Bolivia; ES: Espírito Santo State; GO: Goiás State; MS: Mato Grosso do Sul State; PA: Paraguay; RJ: Rio de Janeiro State; SP: São Paulo State; UR: Uruguay.

references to tooth marks on rocks from South America could not be found, which stimulated the present communication. Furthermore, tooth marks on rocks produced by rodents is very limited worldwide, with only a few contributions (e.g., Cuffey and Hattin, 1965; Gow, 1992; Gobetz and Hattin, 2002).

MATERIALS AND METHODS

Near the Paleontological Site "Fazenda Três Antas" (see Carvalho et al., 2011) in the Municipality of Campina Verde, numerous tooth marks were observed in a sedimentary outcrop that, due to their shape, regular arrangement and size (Figs. 3 and 4), caught our attention. These marks were documented by photographs and a sample was removed and deposited in the collections of the *Complexo Cultural e Científico Peirópolis*, *Universidade Federal do Triângulo Mineiro* (Uberaba, Minas Gerais State, Brazil), under the number CCCP-Zo 0016a. In addition, a silicone positive mold (CCCP-Zo 0016b) was made.

The rocky outcrop is located about 10 km west of Honorópolis town, Campina Verde, Minas Gerais State, Brazil (Fig. 1). This region is an area of pasture with remnant components of the Cerrado Biome (Rosa et al., 1991; Oliveira and Marquis, 2002) (Fig. 2). Climatically, this region is a tropical zone, with a pronounced dry season (May to September) and a rainy season (October to April; Rosa et al., 1991). The

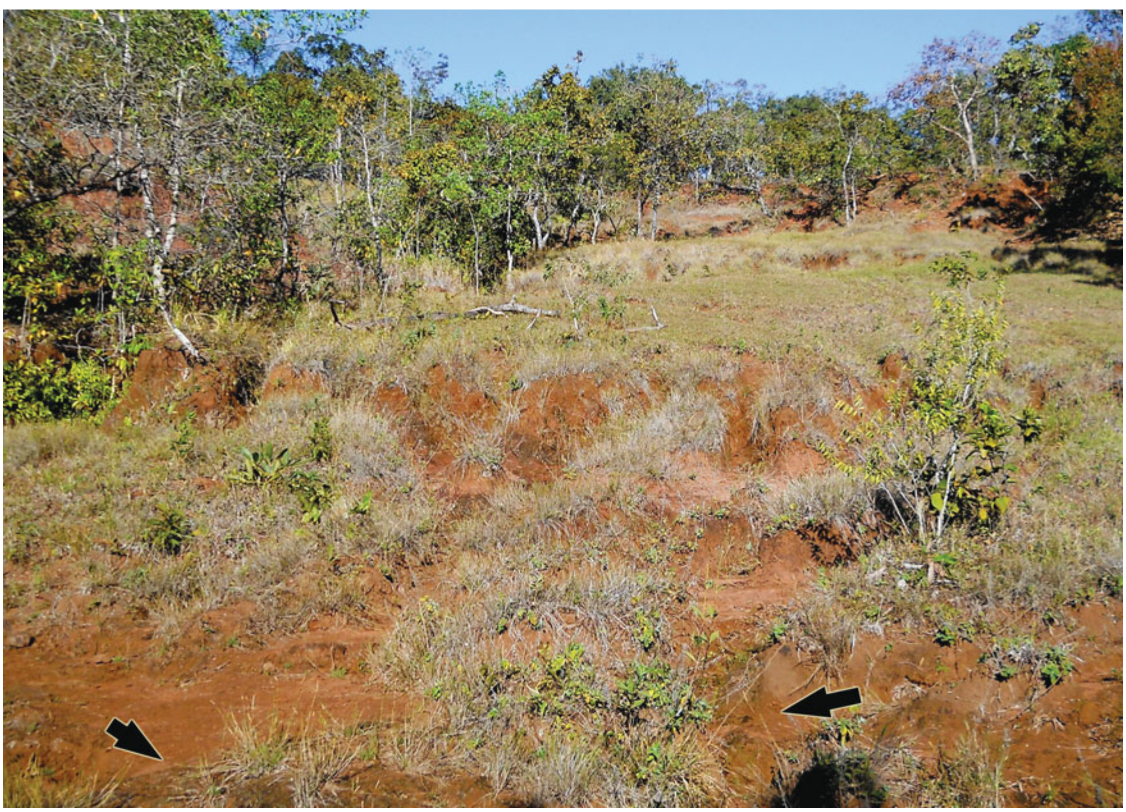

FIG. 2. Environment where the tooth marks were recorded, at the site "Fazenda Três Antas," Municipality of Campina Verde, Minas Gerais State, Brazil. The arrows indicate the sandstone levels of the Adamantina Formation (Bauru Group). Photograph taken in July 2011 (color figure available online).

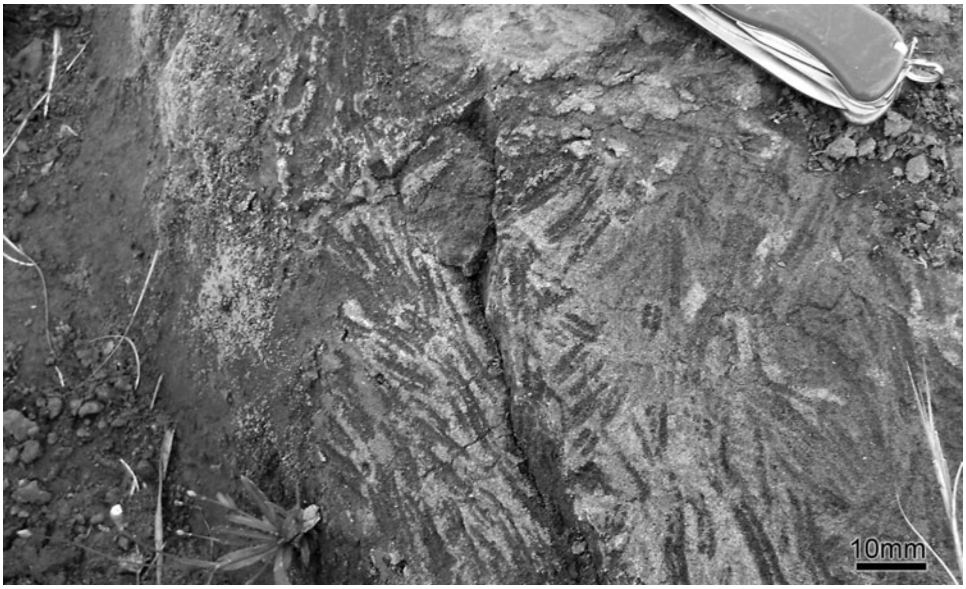

FIG. 3. Vertical wall with tooth marks at site “Fazenda Três Antas.” (See Color Plate II.)

Cerrado flora is an intermediate type between the arboreal and herbaceous vegetation, which can be characterized as wet Savannas, conditioned with alternating wet and dry seasons (Oliveira and Marquis, 2002; Troppmair, 2002). The Cerrado vegetation consists primarily of shrubs and grasses, with scattered, winding low trees in the area, and Gallery forests adjacent to water courses (Art, 1998; Troppmair, 2002).

The tooth marks were produced in a reddish, compact, fine to medium-grained sandstone, with carbonate cementation that belongs to a layer of the Adamantina Formation (Bauru Group, Upper Cretaceous; Fernandes and Coimbra, 1996). In this locality, the sandstone outcrop forms irregular steps ranging from 30 to 60 cm high, crossed by numerous natural drainages (Fig. 2). The top of the sandstone level is covered mainly with

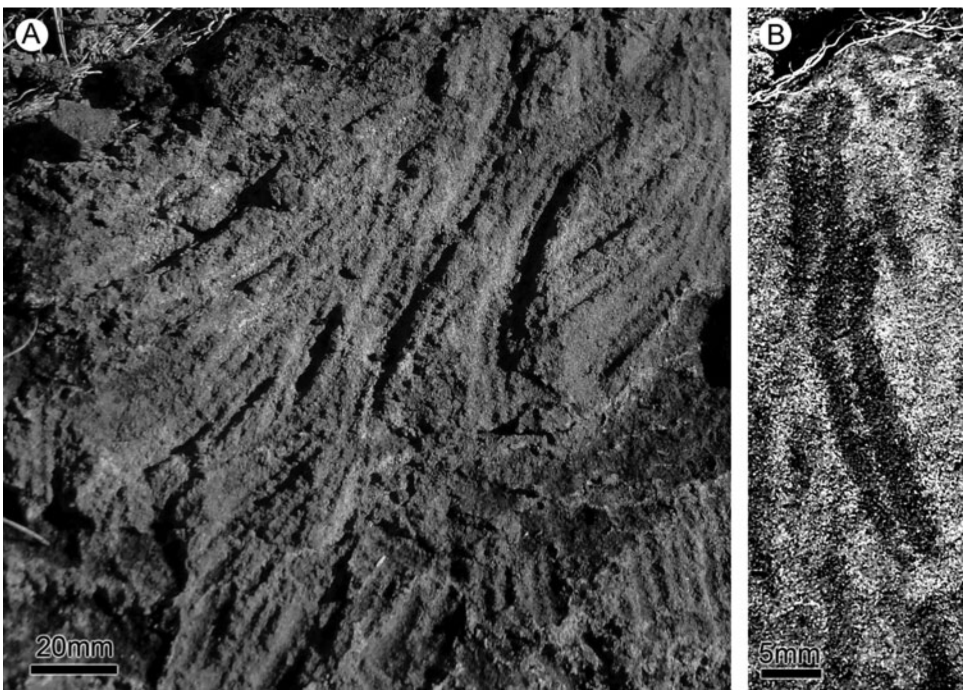

FIG. 4. Tooth marks on the sandstone **(A)** and details **(B)**. Note the prominent medial ridge of the marks. (See Color Plate III.)

grasses and the vertical walls of the steps are occasionally covered with mosses. The area has spring water about 70 m away from the site and a permanent stream about 200 m distant. Near the tooth mark level there are small sporadic ponds.

To identify the mammal that might have produced the marks here presented the following materials were exanimate: Gray brocket deer (*Mazama gouazoubira*: MACN-Ma 53.65, MACN-Ma 32.137), Capybara (*Hydrochoerus hydrochaeris*: MACN-Ma 14039, MACN-Ma 49303), Lowland paca (*Cuniculus paca*: MACN-Ma 50.290, MACN-Ma 49.314), Agouti (*Dasyprocta punctata*: MACN-Ma 50.299; *Dasyprocta azarae*: MACN-Ma 52.51, MACN-Ma 35.12), Brazilian Porcupine (*Coendou prehensilis*: MACN-Ma 50.276), Brazilian guinea pig (*Cavia aparea*: MACN-Ma 23.407), and Brazilian rabbit (*Sylvilagus brasiliensis*: MACN-Ma 23.465, MACN-Ma 36.741). All these taxa are extant in the Triângulo Mineiro region. All specimens are from the *Colección de Mastozoología* (Ma) of the *Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"* (MACN), Buenos Aires, Argentina.

For comparison, artificial tooth marks were made manually (Fig. 5) on clay using the specimens examined at hand: the upper incisors of rodents and lagomorphs and the lower incisors of the gray brocket deer. In addition, an experiment was performed at the "Zoológico Municipal Parque Jacarandá" of Uberaba City, in the precinct of the deer. A ripe pumpkin (Cucurbitaceae) with husk was tied to a wooden base to record possible tooth marks. After 3 days imprinted tooth marks of the incisors were recovered (Fig. 6).

The term tooth mark here refers to the ichno-marks imprinted on a rocky substrate, during gnaw activities. This activity is usually associated with rodents and lagomorphs, which are known to gnaw many types of materials for nutritional purposes or for wearing down their incisors (e.g., Gobetz and Hattin, 2002). Additionally, we also evaluated the "gnawing condition" in the gray brocket deer (Cervidae).

RESULTS AND DISCUSSIONS

The tooth marks are abundant on the sandstone level, located on the subvertical and vertical walls that form the steps (Fig. 2). Two orientations are dominant: perpendicular and sub-horizontal to ground level (Fig. 3). There are sets of marks with the same orientation that could correspond to a single "act" of gnawing. The length of the tooth marks vary from 15 mm to 65 mm long and 5 mm to 6 mm width (Fig. 4). They consist of a central longitudinal ridge that divides two lateral grooves of U-shaped cross-section. The ridge corresponds to the space between the two anterior incisors, and the cavities to the gnawing

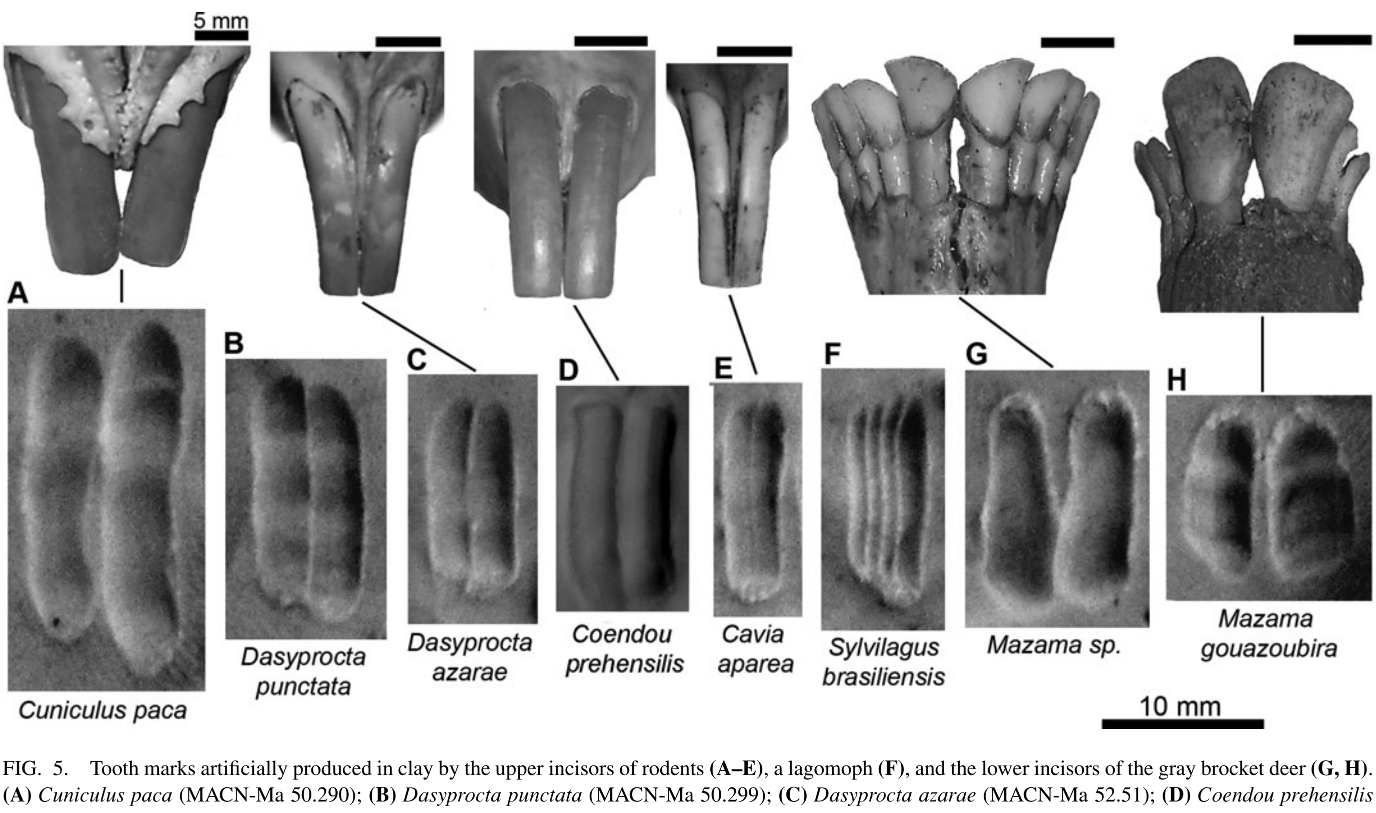

FIG. 5. Tooth marks artificially produced in clay by the upper incisors of rodents **(A–E)**, a lagomoph **(F)**, and the lower incisors of the gray brocket deer **(G, H)**. **(A)** *Cuniculus paca* (MACN-Ma 50.290); **(B)** *Dasyprocta punctata* (MACN-Ma 50.299); **(C)** *Dasyprocta azarae* (MACN-Ma 52.51); **(D)** *Coendou prehensilis* (MACN-Ma 50.276); **(E)** *Cavia aparea* (MACN-Ma 23.407); **(F)** *Sylvilagus brasiliensis* (MACN-Ma 23–465); **(G)** *Mazama gouazoubira* (MACN-Ma 53.65); and **(H)** *M. gouazoubira* (MACN-Ma 32.137). **(A, C–E)** detail of the upper incisors in anterior view; **(G, H)** detail of the lower incisor in ventral view. (See Color Plate IV.)

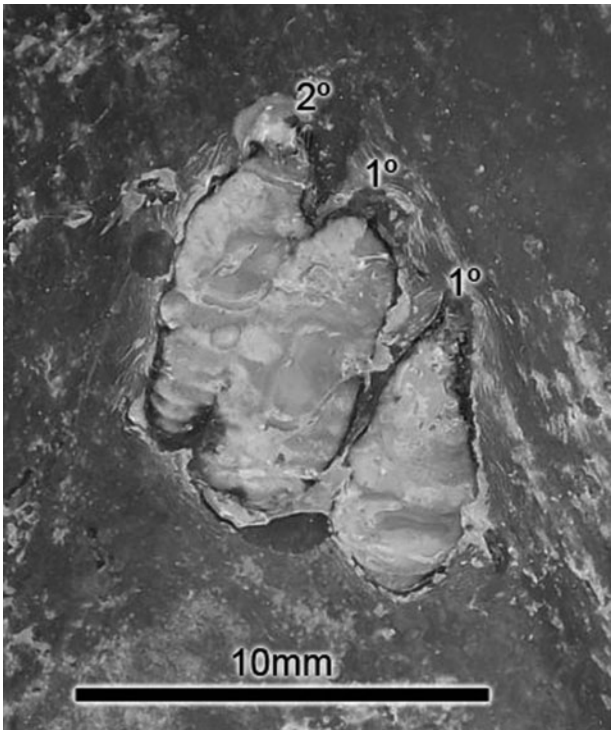

FIG. 6. Tooth marks on pumpkin produced by the lower incisors of a gray brocket deer at the "Zoológico Municipal Parque Jacarandá," Uberaba City, Minas Gerais State, Brazil. The numbers refer to incisor position. (See Color Plate V.)

surface by the cutting edge of each incisor (Figure 4). These marks are clearly the result of gnawing the rock by the incisors of a small to medium-sized mammal, as evidenced by other studies (e.g., Cuffey and Hattin, 1965; Gow, 1992; Gobetz and Hattin, 2002). This sample also suggests gnawing activity by only one species.

In order to evaluate the species that may have produced these marks, several rodents, a rabbit and a deer were used as references (see Material and Methods). Due to the width of the tooth marks of Campina Verde, it is unlikely that they would have been produced by subadult or adult Capybaras (Caviidae, *Hydrochoerus hydrochaeris*). Despite being a relatively abundant species in the Triângulo Mineiro region (Emmons, 1990; Lord, 2009), the width of the two incisors (22 mm) of capybaras is markedly greater than the width of the tooth marks. Other large rodents distributed in this region are the Lowland Paca (Cuniculidae, *Cuniculus paca*), the Agouti (Dasyproctidae, *Dasyprocta azarae*), and the Brazilian Porcupine (Erethizontidae, *Coendou prehensilis*) (Fig. 5). In the paca, the measured width of incisors varies from 8 mm to 9 mm, being slightly larger than tooth marks from Campina Verde. In the agouti, the incisor width is 5 mm, matching the tooth mark here reported. In the observed arboreal Brazilian Porcupine, the width of incisors is 9 mm, but other specimens have slightly narrow teeth. In other rodents, such as the Brazilian guinea pig (Caviidae, *Cavia aperea*), the width of the incisors is noticeably smaller (3–3.1 mm), excluding them from making the tooth marks (Fig. 5). In the Brazilian rabbit (Leporidae, *Sylvilagus brasiliensis*), also common in the region, the main incisors width is 4–4.6 mm, considerably smaller than the tooth marks analyzed. In addition, the incisors have a longitudinal groove in the labial surface on each incisor. Therefore, the expected marks made by this rabbit would be rather different (see Fig. 5F).

Regarding width marks, those artificially produced by *Dasyprocta azarae* are the most similar to the tooth marks here reported. The main difference between *Dasyprocta* and Campina Verde's marks is the medial ridge, separating the grooves for each incisor (Figs. 4 and 5). However, this space may vary individually. In most of the examined specimens of rodents, the cutting edge of the incisors forms a continuous border, leaving a very reduced or absent median space. As such, the imprint of a respective small medial ridge mark on sandstones, under natural conditions, would be quickly eroded. This feature sheds uncertainties when correlating marks of the taxa distributed in the Triângulo Mineiro with the tooth marks of Campina Verde, because it would be expected that rodents would have produced tooth marks with a relatively shallow medial ridge.

Another medium-sized mammal that was observed in the locality during our visits is the gray brocket deer (Cervidae; *Mazama gouazoubira*), also known as "veado-catingueiro" (Portuguese) or "*corzuela parda*" (Spanish). The deer have only four procumbent incisors on each hemimandible, and the first incisor is considerably larger than the others (Figs. 5G, H). The first incisor crown is wide, with the cutting edge convex. The following incisors are smaller and closer together, forming a continuous edge (Figs. 5G, H). The first right and left incisors of each hemimandible contact medially and both are more procumbent than the other teeth.

Both the artificial tooth marks on clay and the natural marks imprinted on the pumpkin at the Zoo produced by the lower incisors of the gray brocket deer have a prominent medial ridge as observed in the tooth marks of Campina Verde. Despite this similarity, the width of the marks is slightly greater, being 9 mm in the artificial one (Fig. 5) and 7 mm on the pumpkin (Fig. 6). In addition, the marks obtained at the Zoo occasionally have an extra groove lateral to the two central ones. This extra mark was not observed in the samples from Campina Verde.

Considering the height of the steps formed in the rocky outcrop where the tooth marks were produced, the rodent *Dasyprocta* and also cervids are in the range of size to have been able to exploit those steps. The moist environment, with permanent streams, abundant grass and dense vegetated areas (i.e., Gallery forest) in the proximity are not exclusive of any of the mentioned taxa. The listed species of rodents and lagomorphs, although distributed in the study area, have not been observed directly at the locality and we did not recognize droppings or footprints belonging to them. During the visit to the site in 2011–2012, footprints and individuals of gray brocket deer were observed. However, this record is not conclusive to identify the animal responsible for the tooth marks.

Although the identification of the gnawing species for these sets of tooth marks are estimates at best, we tentatively suggest that the tooth marks from Campina Verde are most likely the result of the action of the incisors of rodents, such as *Dasyprocta* or *Coendou*.

Tooth Marks and Soil Mineral Nutrients

The soil of the Cerrado is characterized as acid and low in nutrients (Haridasan, 1992, 2008), with a low concentration of essential nutrients such as calcium, magnesium, potassium, and molybdenum (Campillo and Sadzawka, 2006). This type of soil usually has a high concentration of soluble aluminum, which is toxic and easily assimilated by plants and animals (e.g., Campillo and Sadzawka, 2006). The plants present in this environment share the same mineral deficiencies (Haridasan, 2008). Consequently, deficiency of calcium and other minerals (e.g., sodium) in herbivorous animals is common in tropical savanna environments. Under these conditions, mineral supplements are required not only by wild species but also by grazing animals (e.g., Lascano, 1991). Moreover, mineral requirements would be higher in growing juveniles or during pregnancy and/or lactation (Gobetz and Hattin, 2002). To counter the mineral deficiencies of the plants, they feed on soil (i.e., geophagy), which helps to provide the needed minerals, as already mentioned for various wildlife groups in several regions (e.g., Davies and Baillie, 1988; Moe, 1992; Beyer et al., 1994; Houston et al., 2001; Blake et al., 2011). Several studies have also suggested that geophagy helps in detoxifying unwanted components (such as aluminum) present in consumed plants of acid soils (e.g., Brightsmith et al., 2008).

The presence of different types of parasites, such as the protozoan *Giardia*, in the intestinal tract of different taxa, such as the gray brocket deer and capybaras, among others, may cause poor absorption of minerals such as calcium, as well (Gurgel, 2005; Reginatto et al., 2008). Therefore, the deficiencies caused by parasites in wild populations can also provide an incentive to search for supplements in the surrounding environment.

Another little-explored cause is the need for calcium due to contamination by heavy metals, such as lead. It is known that low levels of calcium increase absorption of lead, which is deposited in the bones (Beattie and Avenell, 1992; Skerfving et al., 1993). In this study, it is impossible to assess if the intake of calcium is related to contamination by heavy metals in the region.

The sandstone levels exposed in the locality here reported correspond to the sedimentary Adamantina Formation, Bauru Group (Fernandes, 2004). Within the Bauru Group, different levels are characterized by intense cementation by calcium carbonate ($CaCO_3$) and the concentration of iron oxides in the form of calcrete or as a result of pedogenic groundwater, and/or diagenetic processes (Suguio and Barcelos, 1983; Fernandes, 2004, 2010; Batezelli, 2010). In the site "Fazenda Três Antas," calcium carbonate is abundant as both compact and rigid nodules or homogeneously dispersed at different levels, as is the case where the tooth marks were recorded. For these reasons, external sources of calcium and iron can be found during the disintegration of rocks belonging to the Bauru Group.

The diet of the agouti, the porcupine, and the gray brocket deer includes grasses, legumes, fruits and flowers, depending on the season and availability of food (Richard and Julia, 2001; Black and Vogliotti, 2008). The characteristics of the soil and plants of the Cerrado and the need for extra mineral nutrients (present in the outcrops of this region), provide strong evidences for the origin of these tooth marks in this type of substrate.

CONCLUSIONS

The abundance of tooth marks at the site "Fazenda Três Antas," Campina Verde (Minas Gerais State, Brazil), is well documented. Possibly the hardness of the sandstone is a decisive factor in the preservation of these marks. The limited data on this type of feeding traces (see Gobetz and Hattin, 2002) and associated behavior was the main incentive for the present communication. Although unequivocal correlation of species to tooth marks is not possible, this study provides not only a new record of ichno-marks but also evidence of the use of reddish sandstone substrate, with abundant calcium carbonate, in the Cerrado area of southeastern Brazil. In the collection of the "Museu Arqueológico da Lapinha," Lagoa Santa town, north to the Belo Horizonte city, Minas Gerais State, there are samples of yellowish carbonate rocks with tooth mark of variable sizes extracted from caves from the surrounding area. These samples, which still remain unpublished, contain abundant tooth and claw marks and future studies will provide relevant data on substrate features and correlation of the marks with typical local species.

Because of the concentration of calcium carbonate and other minerals (i.e., iron oxides) in the rocky outcrops of the area, it is possible that wild animals frequently visit these exposures to obtain mineral supplements, according to their individual requirements, and considering the characteristics of the soil and plants of the Cerrado, which are deficient in minerals. Geophagy is common in herbivorous mammals (e.g., tapirs, peccaries, deer, monkeys, cattle) when the food does not provide the necessary micronutrients (e.g., Houston et al., 2001). This site in the Triângulo Mineiro region is clearly an extra mineral source used by wild animals.

Wild animals make use of the available resources in the environment; therefore, similar marks on other types of substrates, depending on the environment, must be common, although the characteristics of the substrate will determine their preservation. The documentation of these marks may be important for future records in other areas, not only in current environments but also for paleobiological interpretations.

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