

# SIGEP

Geological and Paleontological Sites of Brazil

SIGEP 127

## Lajedo de Soledade, Apodi, State of Rio Grande do Norte

*A remarkable megafauna site from northeastern Brazil*

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© Porpino,K.O.; Santos Jr,V.;Santos,M.F.C.F. 2007. Lajedo de Soledade, Apodi, State of Rio Grande do Norte - A remarkable megafauna site from northeastern Brazil *In*: Winge,M.; Schobbenhaus,C.; Souza,C.R.G.; Fernandes,A.C.S.; Berbert-Born,M.; Queiroz,E.T.; (*Edit.*) Sítios Geológicos e Paleontológicos do Brasil. Available on line 31/07/2007 at the address:

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# Lajedo de Soledade, Apodi, State of Rio Grande do Norte

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Lajedo de Soledade (Apodi, state of Rio Grande do Norte, Brazil) is an important paleontological/archeological site in the semi-arid region of Northeast Brazil and a natural monument of rare scenic beauty. It encompasses an extensive karst pavement cut by a remarkable system of ravines developed on a broad carbonatic outcrop of the lower section of the Jandaíra Formation (Upper Cretaceous, Potiguar Basin). Archeological vestiges include ceramic fragments, lithic material from the polished stone phase and rupestrian records. Of these, rupestrian records stand out for their abundance and variety. Paleontological vestiges include remains of Quaternary vertebrates, mainly mammals, occurring in the clastic sediments that fill the ravines, in addition to marine fossils typical of the Jandaíra Formation. Conservation efforts are sponsored by the Fundação Amigos do Lajedo de Soledade (Friends of Lajedo de Soledade Foundation) and by local community involvement.

**Keywords:** Pleistocene; megafauna; taphonomy; archaeology; carstic pavement; Northeastern Brazil.

### INTRODUCTION

Lajedo de Soledade covers an area of around 3 km<sup>2</sup>, and is the largest exposure of carbonatic rocks from the lower section of the Jandaíra Formation, Upper Cretaceous, Potiguar Basin (Bagnoli, 1994). It stands out for the scenic beauty of the karst features, the large number of stone paintings and the fossils preserved in the clastic sediments found in the ravines and small caves located there (Figs. 1 and 2). Thus, it represents a natural monument of great scientific-cultural interest as well as an important tourist attraction.

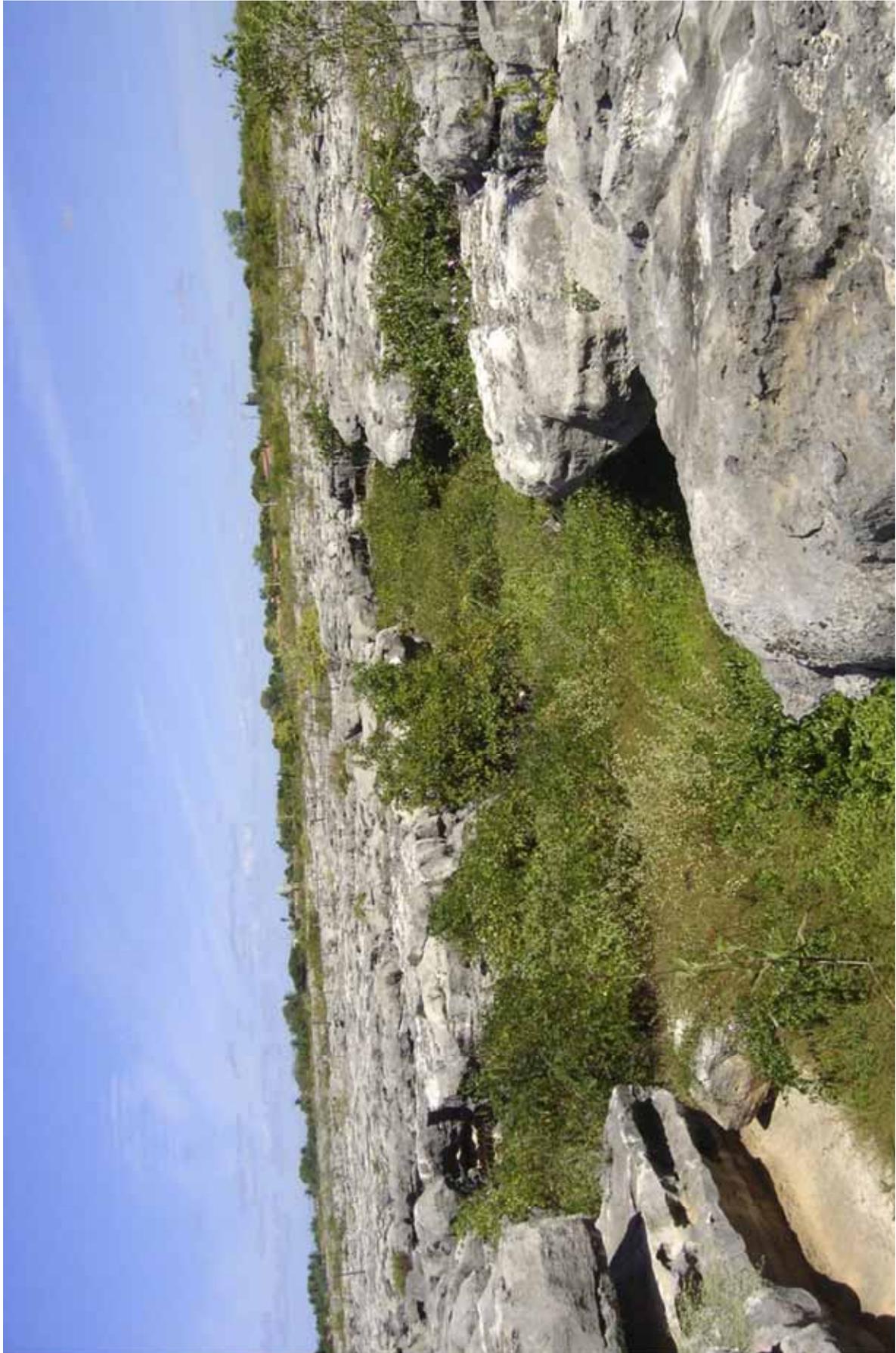
The first references to Lajedo in the specialized literature can be found in pioneer studies on the geology of Northeast Brazil. Crandall (1910) and Sopper (1923) mentioned Lajedo, but without referring to the fossils. Rosado (1957) was the first author to record the occurrence of paleontological material at the site (osteoderms isolated from Glyptodontidae). Later, Souza-Cunha (1966) corroborated this record while exploring the Pleistocene fossil deposits of Rio Grande do Norte. Brief comments and descriptions of local archeological aspects were made by various authors (e.g. Lamartine, 1960; Cabral & Nasser, 1964).

In the early 1990s, systematic studies, conducted by a multidisciplinary team from the Universidade Federal do Rio Grande do Norte (UFRN) and the Universidade Federal de Pernambuco (UFPE), were performed at the site. Field studies resulted in the collection of a significant amount of Quaternary

vertebrate remains, mainly mammals and enabled more detailed knowledge of local archeology. During these activities, paleontological collection was made mainly in one of the ravines (Leon ravine), from where most of the paleomastozoological information on Lajedo de Soledade derives (Fig. 2). Recently, the paleomastozoological material collected at Lajedo was identified at the family level by Santos et al. (2002a) and described and discussed in more detail by Porpino et al. (2004). Santos et al. (2002b) described and interpreted a number of biostratigraphic and fossil-diagenetic features of these fossils from observations of macroscopic taphonomic signatures and thin section analysis. Geological studies to characterize and define sedimentary structures and facies, in addition to the paleoenvironmental interpretation of Lajedo rocks, were performed by Bagnoli et al. (1994), Córdoba et al. (1994), Apoluceno et al. (1995) and Córdoba & Souza (1997).

### LOCATION

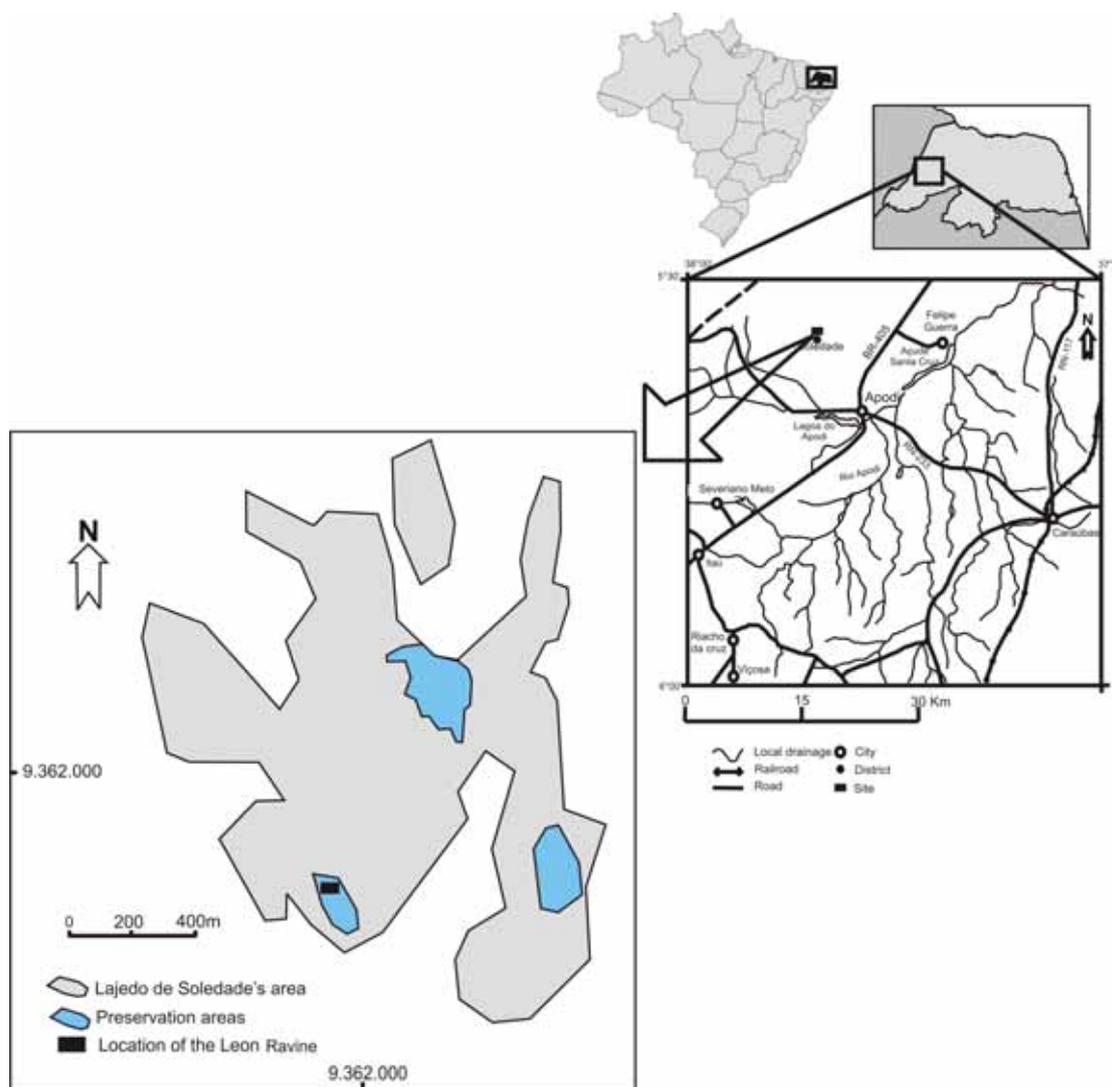
Lajedo de Soledade (05°35' S and 037° 48' W) is located in the southeast portion of the Potiguar Basin, in the district of Soledade, municipality of Apodi, in the western region of the state of Rio Grande do Norte (Fig. 3). It lies 6 km from the town and 420 km from Natal, the state capital. It can be reached by taking federal highway BR-304 from Natal to Mossoró, followed by BR-405 to the entrance of the settlement of Soledade and finally to neighboring Lajedo.



**Figure 1** – Panoramic view of Lajedo de Soledade.



**Figure 2** – Lajedo de Soledade; **a.** Aerial panoramic view SSE; **b.** A ravine details.



**Figure 3** – Map of Lajedo de Soledade and site diagram modified from Santos et al. (2002) and Córdoba & Souza (1994).

## SITE DESCRIPTION

### Geomorphological and environmental aspects

The regional relief includes two main geomorphological units: the Chapada do Apodi and the Depressão Sertaneja. The Chapada do Apodi, where Lajedo is located, is situated between the lower stretches of the Jaguaribe and Assu Rivers, and is cut by the Apodi and Upanema Rivers (Beurlen, 1967). Its surface is flat, with elevations of around 100 m. In addition to the site in question, there are several other karst pavements, some bearing speleologic deposits with significant paleontological record, such as Lajedo da Escada, municipality of Baraúna (Carvalho et al., 1966). The Depressão Sertaneja contains the lowlands between the most elevated portions of the Chapada do Apodi and the Planalto da Borborema.

The region is located in the morphoclimatic domain of the Brazilian Caatingas (*sensu* Ab'Saber, 1974). The climate is semi-arid, with high mean annual temperatures (28.1°C) and predominantly

hyperxerophilic Caatinga, with an abundance of cacti and shrubs (IDEMA, 1999).

### Geology

Lajedo de Soledade is a broad karstic pavement formed by carbonatic rocks (calcarenites and subordinate dolomites), lithostratigraphically included in the Jandaíra Formation, which is composed of carbonates belonging to the transgressive sequence (Albian-Campanian) of the drift phase of the tectono-sedimentary evolution of the Potiguar Basin (Pessoa-Neto, 2003). Bagnoli et al. (1994) inferred that the rocks of Lajedo de Soledade were a system of ebb tide bars. Later studies concluded that these bars were deposited under conditions of shallow water lamina, in the infratidal zone of a tidal plain system, on a coast with bay or estuary physiography where the ebb tides were the predominant regime (Apoluceno et al., 1995; Bagnoli et al., 1994; Córdoba et al., 1994).

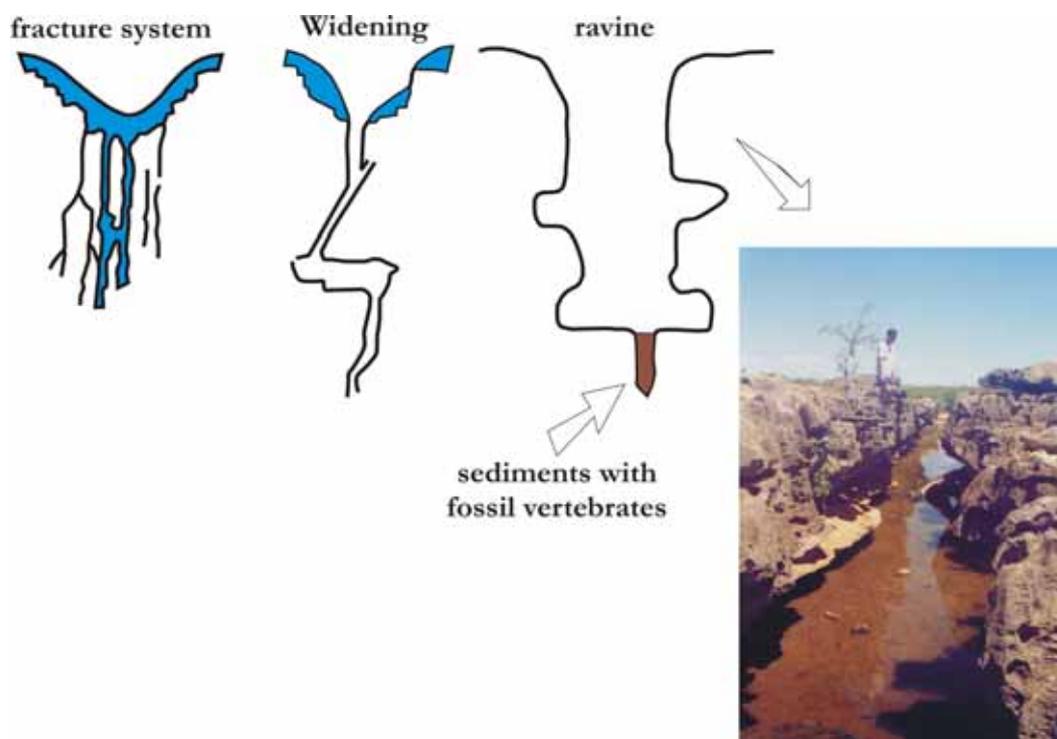
The rock formation is cut by several faults and fractures mainly NE/SW and NW/SE, which enable

the development of ravines and small caves as a result of an intense karstification process. The existence of these ravines, which are natural trenches, allows three-dimensional visualization of the faciological variation, sedimentary structures and geometry of the bodies. Two main depositional facies were identified: the first consists of grainstones and packstones with trough, tubular and low-angle cross-stratification, in addition to other structures typical of tidal plains (cross-stratifications with reverse ripple marks and mud couplets); the second is represented by packstones and strongly bioturbate and occasionally dolomitized wackestones (Córdoba & Sousa, 1997).

According to the evolutive model proposed by Santos (2001), adapted from White (1988), establishing the aforementioned fracture system enabled the passage of water rich in acid solutions,

promoting the widening of troughs by the dissolution of carbonate, thereby giving rise to the ravines (Fig. 4). The width and depth of these ravines are variable and exhibit different stages of development. They are filled, to a lesser or greater extent, by clastic sediments characterized by the presence of quartz grains with a low degree of roundness, indicating little transport from the nearby source area. In addition to the ravines, there is a karst source in the Lajedo area where fossils were collected by Rosado (1957) and Souza-Cunha (1966).

The most significant ravines from the paleontological, archeological or landscape viewpoint were named locally. These include the Urubu ravine, Dodora ravine, Peninha ravine and Leon ravine. The latter was the main paleontological material collection point of Lajedo.



**Figure 4** – Evolutive model for the Lajedo de Soledade ravines. Modified from Santos (2002a) and White (1988)

### Archeology

Three types of archeological vestiges were identified at Lajedo de Soledade: ceramic fragments, lithic material from the polished stone phase and rupestrian records.

The ceramic fragments exhibit four decorating techniques: unglazed, brushed, corrugated, and incised. The wrapped twining technique was used in the ceramic manufacture process. Morphologically, few bowl or base fragments were identified, precluding any functional contextualization. Some of these fragments displayed red paint remnants. Because of the small amount found in excavations, precise

dating of the ceramic was impossible to establish (Albuquerque & Pacheco, 2000).

The most abundant archeological vestiges at Lajedo de Soledade are the rupestrian records (Fig. 5), which appear as two different types: paintings (found in 30 areas of Lajedo) and engravings (found in 26 areas).

The paintings were made predominantly in red, followed by yellow and black. Five techniques were used: fingertips, small twigs, primitive brushes, ochre or charcoal sticks and hand prints.

These paintings, mainly pure graphism (rupestrian records that preclude any type of interpretation and/or recognition in view of our sensitive reality,

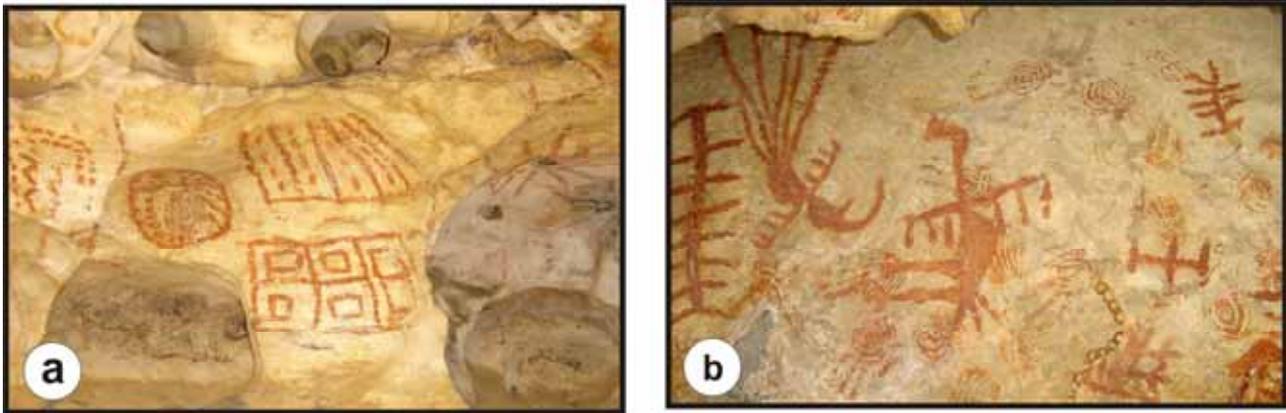
according to Martin, 1999) and rare zoomorphic manifestations, can be seen only at determinate Lajedo ravines, which had been previously prepared by breaking their edges. Because these paintings and certain themes are limited to a number of specific ravines of Lajedo de Soledade, Albuquerque & Pacheco (2000) suggested that these were ceremonial sites. Another factor that reinforced this hypothesis is its seasonal characteristic: Lajedo de Soledade was not permanently inhabited by the creators of the paintings, since the ravines are subject to flooding during the winter, making their visitation possible only at specific times of the year.

The Lajedo de Soledade was preliminarily interpreted as a likely ceremonial site of the Agreste tradition tribes (Martin, 2000). However, the paintings located there cannot be included in this tradition, given the regional specificities in classifying these records. Their thematic representations are unique and must have been created by local prehistoric groups, given that no graphic similarity was found

with the other archeological sites of Chapada do Apodi containing rupestrian records.

In chronological terms it was not possible to implement any direct or indirect dating method that could estimate the age of the Lajedo paintings. The raw material of the paintings consisted of common inorganic products found in the region (iron oxide), hindering the use of current direct dating methods. A comparison, in terms of thematic and technique similarities, with other northeastern archeological sites containing previously studied rock paintings, to indirectly correlate their age is neither feasible nor chronologically reliable.

With respect to the lithic material located in the excavations, few artifacts from the polished stone phase were collected, suggesting the presence in the region of prehistoric groups that engaged in agriculture. As with the ceramic fragments, they may have been carried away by rainwater, preventing any type of chronological correlation with the rock painting groups.



**Figure 5** – Examples of rock paintings from Lajedo de Soledade. a. Geometric figures; b. Zoomorphic figures

## Paleontology

In the walls and pavements of some ravines and along the surface of Lajedo can be found ichnofossils (trace fossils) of the ichnogenus *Thalassinoides*, gastropod and equinoderm remains, as well as fish teeth, examples of the rich marine fauna that existed during carbonate deposition at Jandaíra Formation.

Quaternary vertebrate remains (Fig. 7), represented by varied postcranial bones, dental fragments, isolated teeth and osteoderms, were collected in clastic sediments that fill the ravines and correspond to the most significant macropaleontological vestiges of Lajedo. The material is composed mainly of small dark brown or black elements, some of which form small ferrous concretions and bone breccia. Curiously, there is a scarcity of large bones, considering the presence of large mammals in local fossil assemblages. Santos et al. (2002a) interpreted this evidence as a preservational

artifact produced by fossil deposition at an early stage of ravine development, when the likelihood of retaining larger fragments would be lower. In addition to the well preserved remains, there is a large amount of indeterminate bone fragments (Santos, 2001; Santos et al., 2002b).

In regard to the diagenetic aspects of vertebrate fossils, thin section analysis allowed Santos et al. (2002b) to determine the occurrence of permineralization and substitution in the collected material (Fig. 6), sometimes occurring simultaneous in a same specimen. Pore-filling is, in some cases, formed by a greenish sandy-clayish mass containing quartz grains in the silt and middle sand fractions, where angulated micro bone fragments can be observed randomly distributed (Santos, 2001; Santos et al., 2002b). In other situations a total filling of bone porosity by  $\text{CaCO}_3$  crystals can be observed. Ferruginous material precipitation in the contacts between the carbonatic crystals can also occur.

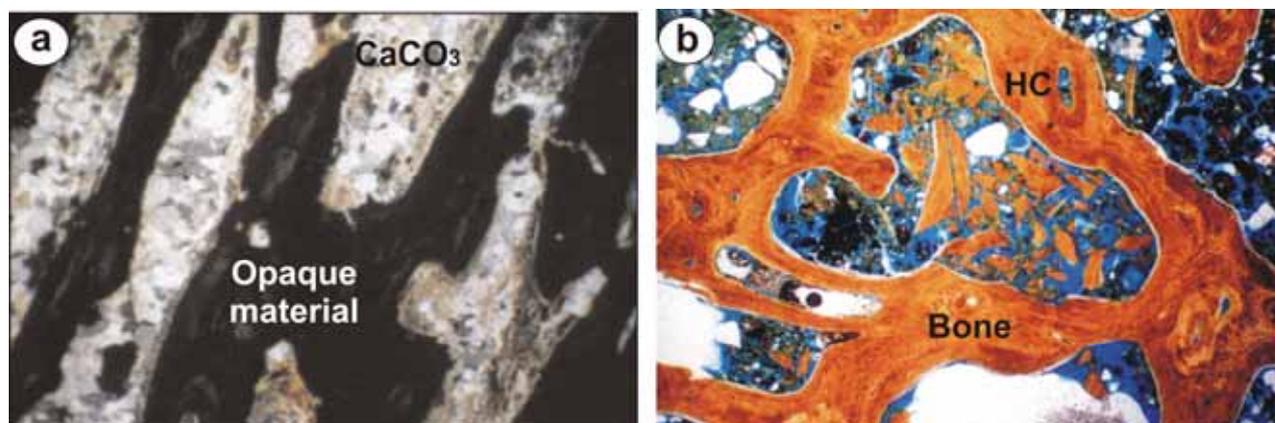
Substitution, showing variable intensity in different samples, was made by iron oxides occurring frequently in the Lajedo as small concretions or ferruginous crusts (Fig. 6a).

The mammalian fossils collected in the ravines (Figs. 7a-c,e,f) comprise small, medium-size and large species (Megafauna), included in the following families: Megatheriidae (*Eremotherium laurillardii*), Glyptodontidae (*Panochthus greslebini*, *Glyptodon* sp.), Dasypodidae (*Tolypeutes tricinctus*, *Holmesina paulacoutoi*), Canidae (*Cerdocyon thous*, *Procyon troglodytes*), Felidae (*Smilodon populator*, *Leopardus* cf. *L. tigrinus*), Ursidae (*Arctotherium* sp.), Equidae (*Hippidion* sp., *Equus* (*Amerhippus*) cf. *E.(A.) neogaeus*), Camelidae (*Palaeolama major*) Macraucheniidae (*Xenorhinotherium bahiense*), Toxodontidae indet., Cervidae and Gomphotheriidae (Porpino et al., 2004; Santos et al. 2002a). *Leopardus* cf. *L. tigrinus*, *Arctotherium* sp. and *P. troglodytes* are exclusive to Lajedo, given that there are no known

occurrences in other quaternary deposits in the state. In addition to the mammals, crocodylomorph osteoderms (Santos et al. 2002a) and indeterminate ophidian vertebrae were collected

The paleomastofauna of Lajedo shows a taxonomic composition similar to that of other regional quaternary deposits. For this reason, taking into account mainly the presence of *E. laurillardii* and *P. greslebini*, Porpino et al. (2004) attributed the fauna to the Late Pleistocene-Holocene, in accordance with the model proposed by Cartelle (1999) for the intertropical extra-Amazon Pleistocene of Brazil.

The mammals identified were grazing megaherbivores and grazers/browsers, in addition to more generalist forms, with preferences for forests or ecotone areas, suggesting a savanna paleoenvironment associated to more closed phytophysiognomies than those of today for the Late Pleistocene-Holocene of the Lajedo de Soledade region (Porpino et al., 2004).



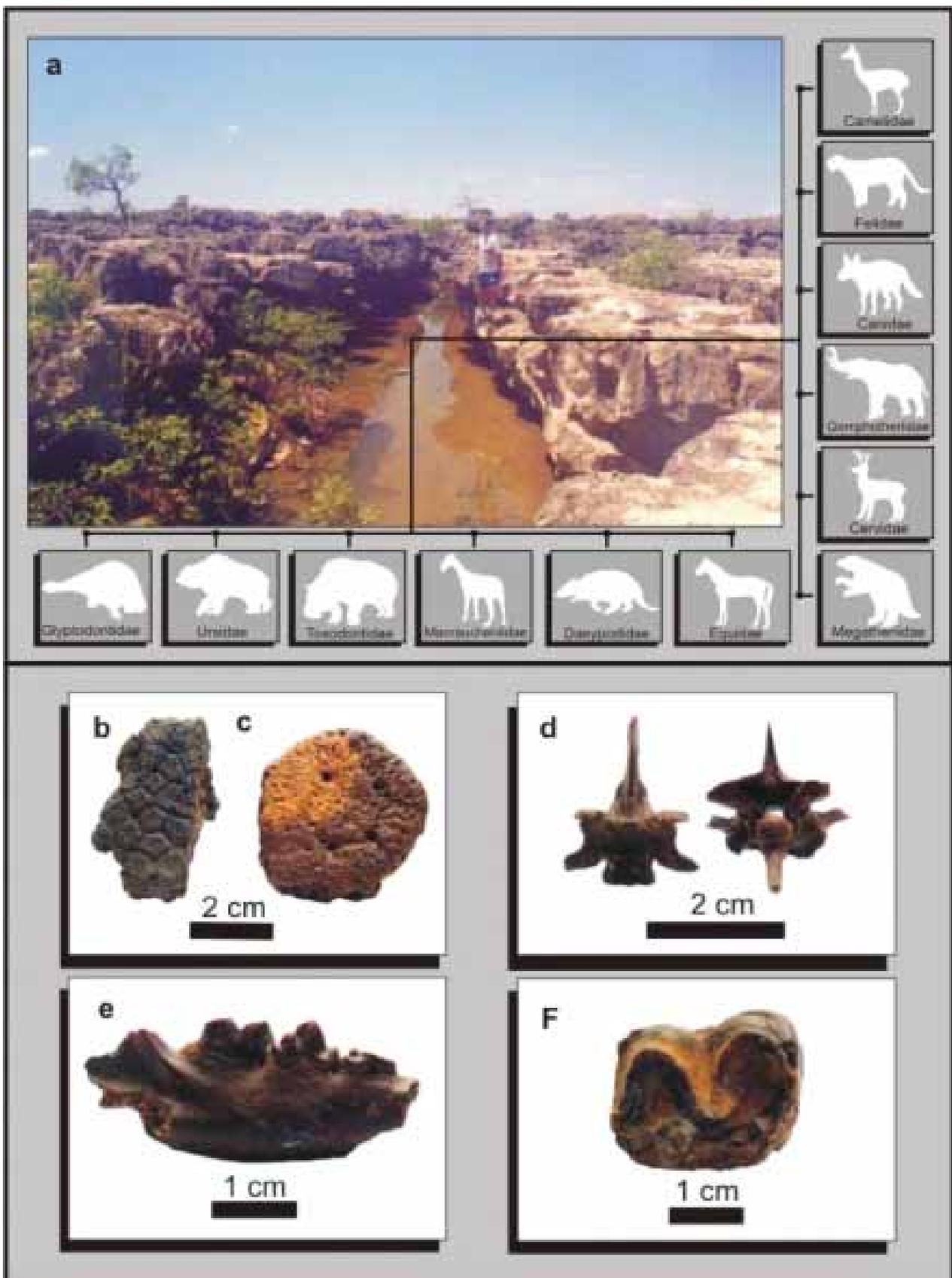
**Figure 6. a.** Bone substitution by opaque material and porosity filling by CaCO<sub>3</sub> crystals. 14mm X21mm. Crossed nichols. 4x.; **b.** Bone porosity filled by bone fragments mixed with claysh material; CH= haversina channels 14mmX21mm. 4x. Modified from Santos et al. (2002b)

## SYNOPSIS OF THE ORIGIN, GEOLOGICAL EVOLUTION AND IMPORTANCE OF THE SITE

The carbonatic rocks that form the Lajedo de Soledade belong to the Jandaíra Formation (Potiguar Basin) and were deposited during the late Cretaceous period under shallow water lamina conditions in a tidal plain system. These sediments, already compacted in rocks, were uplifted above sea level and exposed to erosion in the late Mesozoic (Mesocampanian). The percolation of water through NE/SW and NW/SE fractures enabled the dissolution of carbonate rocks, producing an extensive system of ravines (Fig. 4), some reaching depths of more than eight meters.

In the ravines already formed or in the formation process, sediments containing fossils from the late

Pleistocene-Holocene were deposited, likely owing to the action of flash floods. These fossils correspond to remains of large mammals (giant sloths, mastodonts, glyptodonts, toxodonts, among others) and of small and medium-sized species, including *Arctotherium*, a small short-faced bear. In addition, crocodile and snake remains also occur. The preserved bones show signs of size selection during the depositional processes, where teeth, bones from small and medium-sized species and small bones from large species predominate. After burial, the bones had their pores and microcavities filled with sediments and, in some cases, the original inorganic bone matrix was substituted by opaque material. The fossils of the rich marine fauna of the Jandaíra Formation are incorporated into the rocks of the Lajedo and are represented by shells and ichnofossils produced by invertebrates and some fish teeth.



**Figure 7** – Fossil vertebrates from Lajedo de Soledade. **a.** Fossil mammals families of the local-fauna from Lajedo de Soledade, modified from Santos et al. (2002a); **b.** Osteoderm of *Panochthus greslebini*; **c.** Osteoderm of *Glyptodon*; **d.** Ophidian vertebra; **e.** Dentary of *Leopardus*; **f.** Lower molariform of *Xenorhinotherium bahiense*.

The ravines and small caves of Lajedo were likely used as temporary shelters by prehistoric populations of Northeast Brazil, leaving a rich cultural heritage consisting of lithic material, ceramic fragments and a large amount of beautiful paintings and engravings that decorate the walls of many ravines.

In summary, the Lajedo de Soledade is an important geoscientific and cultural site, owing to its unique combination of characteristics, including a wide diversity of geological features produced at different moments of its evolution, an abundance of fossils with interesting preservational features and a significant and original archeological record.

## PROTECTION MEASURES

### Current measures

For a long time the local exploitation of carbonate rocks, mainly for the manufacture of lime used to whitewash walls, posed a threat to Lajedo de Soledade. However, thanks to the initiative of the Petrobras Oil Company in the early 1990s, preservation areas were established. Later, Petrobras provided logistics and financing for scientific studies in the area and for the construction of a museum (Museum of Lajedo de Soledade), inaugurated in 1993 and currently housing the pieces recovered from Lajedo. Tourist and educational visits are also organized.

Indispensable support is also provided by the Friends of Lajedo de Soledade Foundation (FALS), a non-profit civil entity created in 1990 to protect the historical and cultural patrimony of Lajedo. FALS is presided by the environmentalist and historian Maria Auxiliadora da Silva Maia; its website ([www.lajedodesoledade.org.br](http://www.lajedodesoledade.org.br)) offers information on Lajedo, emphasizing its scientific-cultural importance. Moreover, it is important to underscore the participation of the local inhabitants as tourist guides, curator of the museum collection and in other parallel activities (for example handcrafts) derived from the establishment of the museum. This local community involvement is fundamental to ensure the continuity of current preservation measures.

### Authors' suggestions

The existing measures have been implemented with efficiency and control, as attested by the authors in their research and field studies in Lajedo. It is suggested, however, that greater investment be made in publicizing the site to ensure its inclusion as a state tourist attraction. To date, priority has been given to coastal areas and to those near urban centers. Participation by the state government, through the support of economic and cultural activities related to

Lajedo, is essential to strengthen local social and economic development.

## ACKNOWLEDGEMENTS

We are grateful to the geologist Leonardo Morato for his suggestions and to Professor Dr. Ramiro Valera Camacho, Department of Biological Sciences at the Universidade do Estado do Rio Grande do Norte, for kindly providing the aerial photograph of Lajedo de Soledade and to Mr. Michael Germain for helping with the English language version of this article.

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### AUTHOR'S SYNOPTIC CURRICULUM VITAE



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