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Titanosaur (Dinosauria: Sauropoda) Osteoderms from the Maastrichtian of Uberaba, Minas Gerais State, Brazil

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Abstract

Titanosaur remains are common findings at the paleontological site of Peirópolis in Uberaba. Among those remains, two osteoderms referred to titanosaur sauropods were reported. Both dermal bones share many features, such as the coarse texture, parallel ventral grooves, lack of the *cingulum* and presence of a ventral ridge (crest). Armored titanosaurs had wide distribution in the Upper Cretaceous, and have been reported from Argentina, Brazil, France, Madagascar, Malawi, Romania and Spain. In the present work we describe and compare the Brazilian titanosaur osteoderms found thus far.

Key words: Dinosaur, titanosaur, osteoderm, Late Cretaceous, Uberaba.

Introduction

Armored sauropods were known worldwide during the Late Cretaceous. Sauropod osteoderms are known to date from Argentina, Brazil, France, India, Madagascar, Malawi, Romania and Spain (e.g., Bonaparte and Powell, 1980; Salgado and Coria, 1993; Azevedo and Kellner, 1998; Le Loeuff et al., 1994; Dodson et al., 1998; Csiki, 1999). Charles Déperet (1896) was the first to ascribe an osteoderm to a titanosaur, even it was tentative at that date, and it was eventually confirmed later. The best-known records of these dinosaurs are from Argentina, from which came the first well supported evidence that sauropods could be osteoderm bearers (Bonaparte and Powell, 1980). Most of those armored sauropods were titanosaurs, such as *Magyarosaurus dacus*, *Saltasaurus loricatus*, and *Aeolosaurus rionegrinus*. Some non-titanosaur sauropods also had dermal ossifications, such as diplodocids and *Agustinia ligabuei* (Czerkas, 1992; Bonaparte, 1999). The record of titanosaur osteoderms from Brazil is scant, and is based only on two isolated remains from Marília Formation at Peirópolis, State of Minas Gerais (Azevedo and Kellner, 1998; Marinho and Candeiro, 2003). The genus *Aeolosaurus* was reported in Los Alamitos and Allen Formations of Argentina (Salgado and Coria, 1993), and was recently identified in the same strata in which the Brazilian osteoderms were discovered (Santucci and Bertini, 2001; Santucci, 2002). These findings corroborate the presence of titanosaur osteoderms in the Marília Formation.

Geological Setting

Both osteoderms described in this work were discovered at the paleontological site of Peirópolis, Municipality of Uberaba, State of Minas Gerais (Fig. 1). The outcrops at this site are regarded as the Marília Formation (Fúlfaro and Barcelos, 1991), Serra da Galga Member, upper strata of the Bauru Basin, (*sensu* Fernandes and Coimbra, 1996). Locally, the Marília Formation (Maastrichtian) is deposited above the Uberaba Formation (Turonian–Santonian), (Dias Brito et al., 2001).

The Serra da Galga Member is characterized by calciferous sandstone, deposited in a fluvio-lacustrine environment, showing cross-stratification and conglomeratic sequences in which the fossils are usually found (Barcelos, 1984).

Systematic paleontology

Order Saurischia Seeley, 1889

Suborder Sauropoda Marsh, 1878

Titanosauria Bonaparte and Coria, 1993

Gen. et sp. indet.

Repository: The described and figured materials are housed at Centro de Pesquisas Paleontológicas Llewellyn Ivor Price, Peirópolis, Uberaba, Minas Gerais State, Brazil.

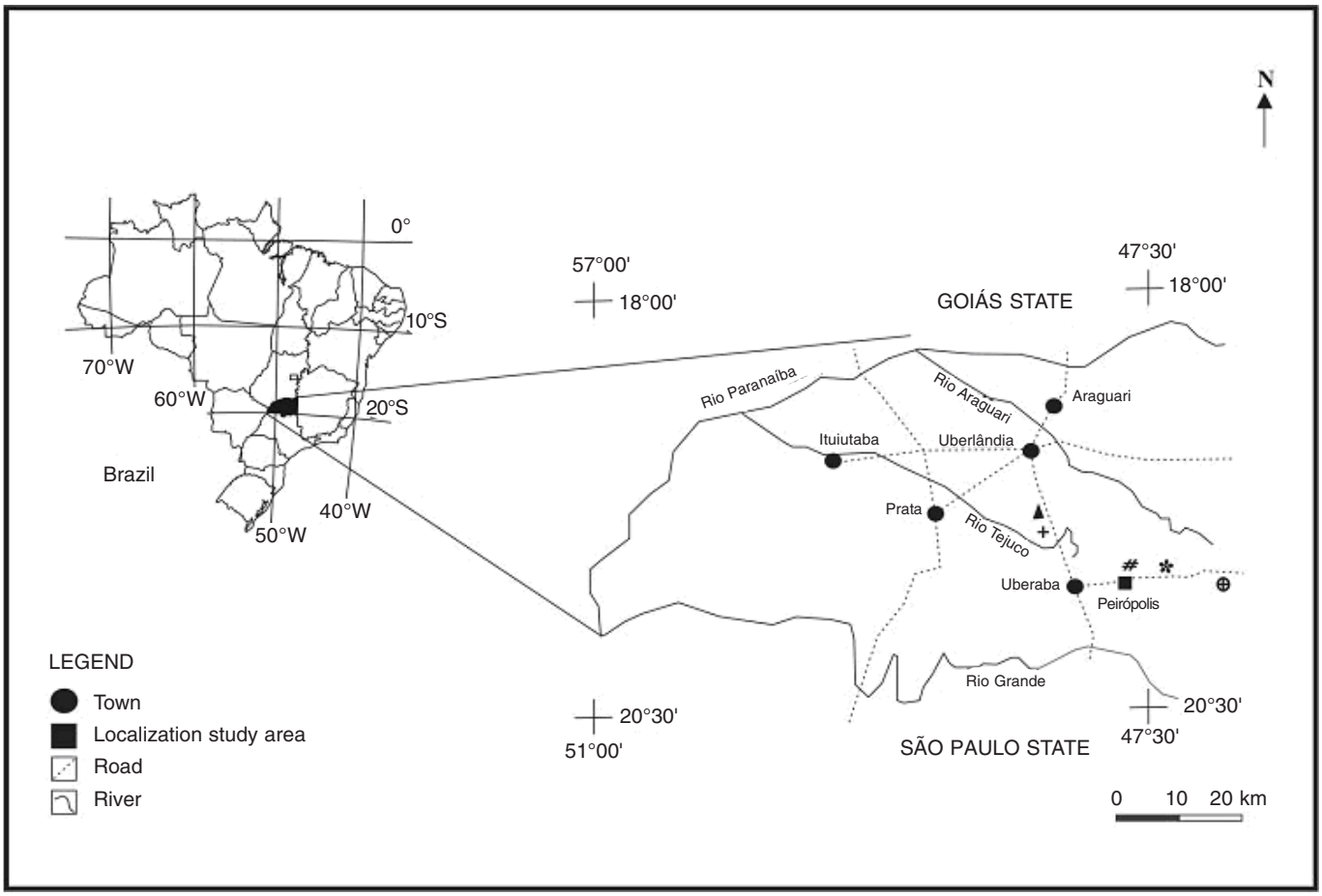

Fig. 1. Geographic location of the paleontological site at Peirópolis, Minas Gerais State, Brazil.

Institutional: CPP, Centro de Pesquisas Paleontológicas Llewellyn Ivor Price.

Locality and horizon: CPP-297 and 674 come from the Serra da Galga Member of the Marília Formation from the outcrop known as "Ponto 1 do Price" at the Peirópolis Site, Minas Gerais State, Brazil.

Description: CPP-297 was briefly described by Azevedo and Kellner (1998) and here we extend the description of this bony plate. The osteoderm is oval, and is smaller than that reported by Marinho and Candeiro (2003). As observed in other titanosaur osteoderms, CPP-297 has a coarse texture, especially on the dorsal surface (Fig. 2a). There are pits randomly distributed on the dorsal surface. Grooves are found all over the material as observed by Azevedo and Kellner (1998), but they are generally dorso-ventrally oriented. The main feature characterizing the ventral surface (Fig. 2b) is the presence of several small (about 1 mm and 2 mm), round, vascular foramina, the largest one ending in a deep canal (Azevedo and Kellner, 1998). Shallow parallel grooves compose an interwoven pattern. The same pattern is observed in the titanosaur osteoderms from Madagascar (Dodson et al., 1998) which corroborate the ventral position (Fig. 2c) of this surface. Ventrally, CPP-297 has a discrete ridge that separates it in two asymmetric flat parts, (Azevedo and Kellner, 1998). Tiny projections can be seen randomly distributed on the ventral surface. The dorsal surface is convex, and has the maximum thickness in the middle of the dorsal surface. A distinct longitudinal ridge cannot be observed, but rather a low dorso-ventrally flattened area. The osteoderm is broken from the dorsal to the ventral surface, revealing the internal portion composed of spongy bone tissue, and the same is seen in the other osteoderm described in this work. The internal portion of this osteoderm is composed mainly of spongy bone, resulting in low density.

CPP-674 is a 'D'-shaped osteoderm in dorso-ventral view. It is very well preserved and no weathering process can be seen on it. Some features of CPP-674 closely resemble those in CPP-297, but the thickness is proportionally greater for this new specimen. As seen in other titanosaur osteoderms, the dorsal surface (Fig. 3b) is coarse with randomly distributed pits, grooves, and a nearly median ridge that gives this specimen a highly convex dorsal surface, similar to other titanosaur

osteoderms (e.g., Le Loeuf et al., 1994; González Riga, 2003). The ventral surface (Fig. 3a) in this specimen is also characterized by round and oval foramina (ranging from 2 mm to 8 mm in diameter, the biggest ones situated in a latero-basal position) and the parallel grooves that resembles the fibrous (Fig. 3c) interwoven bone noted by Sanz and Buscalioni (1987), Le Loeuff et al. (1994), and Dodson et al. (1998) for titanosaur osteoderms. This interwoven pattern is also seen on the internal (ventral) surface of the osteoderms of crocodilians and certain dinosaurs, notably stegosaurs and ankylosaurs (e.g., Mook, 1921; Gilmore, 1914; Blows, 1987). Also on the ventral surface, a discrete nearly median ridge can be seen. CPP-674 is also broken on the dorsal surface, revealing the spongy bone that composes its internal portion. Part of the edge is round, and one side is straight, which gives the osteoderm the capital 'D' shape. The straight side of the 'D' provides a transverse view of a flat fibrous surface (Fig. 3c) that may be related to vascular functions and maintenance of the bone tissue or a surface where it could articulate to another osteoderm.

Discussion

The fossil remains from Marília Formation at Uberaba consist mainly of disarticulated titanosaur bones. Recently, the genus *Aeolosaurus* was identified from those materials housed at the Centro de Pesquisas Paleontológicas Llewellyn Ivor Price (Bertini et al., 2000; Santucci and Bertini, 2001; Santucci, 2002). This finding is based on postcranial elements which were collected at the same site were the osteoderms were unearthed. The presence of *Aeolosaurus*, an armored titanosaur, (Salgado and Coria, 1993), corroborates the hypothesis that the armored titanosaurs that lived during the Late Cretaceous at Uberaba. *Aeolosaurus* osteoderms resemble both CPP-297 and CPP-674 in some features like the lack of *cingulum* and asymmetric rhomboid look. Crocodylomorph remains are abundant at this locality, and osteoderms of this group are frequently found. The lack of a distinct pit pattern as in crocodilian osteoderms (Dodson et al., 1998), the presence of internal ducts, (Le Loeuff et al., 1994) and the porous internal bone structure observed on CPP-297 and CPP-674, suggest that these osteoderms cannot be attributed to any known crocodylomorph. An important autapomorphy of titanosaur osteoderms is the presence of a ventral ridge or crest (Salgado, 2000), clearly preserved in both CPP-297 and CPP-674. Nodosaurid (Ankylosauria) osteoderms could be mistaken for the titanosaur ones, but the ventral surfaces of the osteoderms of those animals lack the apomorphic ventral crest of titanosaurs (Pereda-Suberbiola,1993).

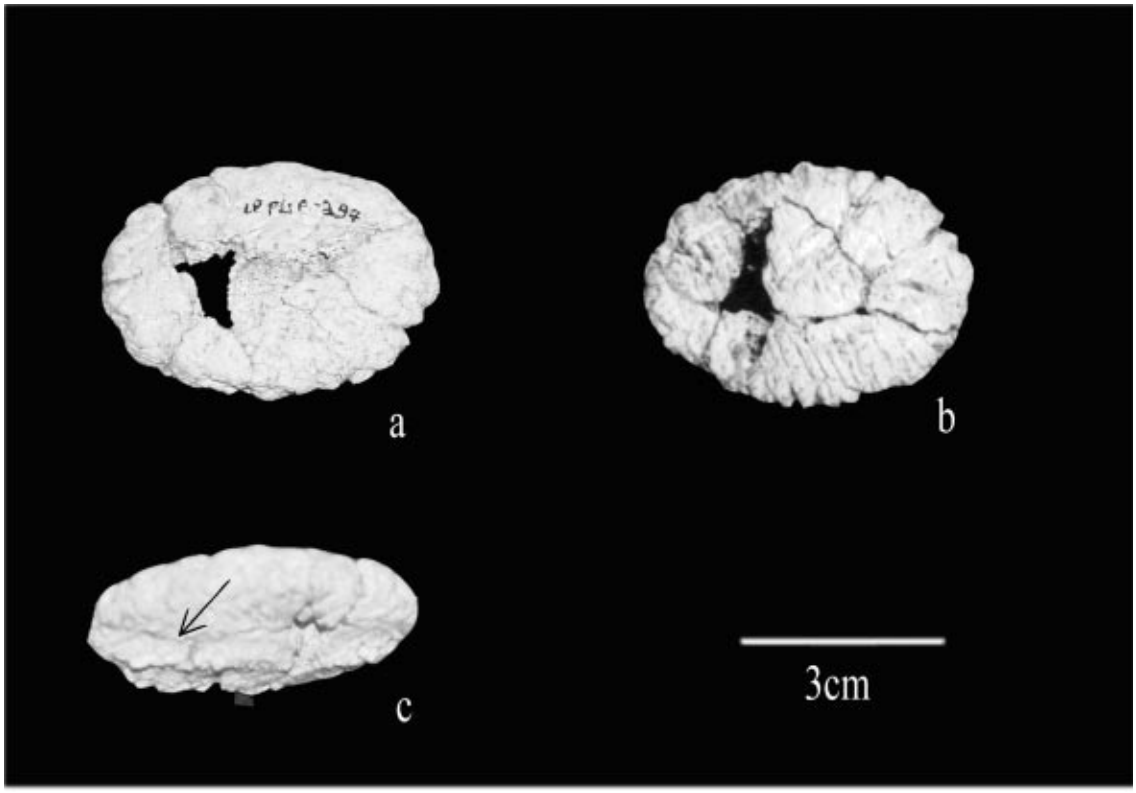

Fig. 2. Titanosaur osteoderm, CPP-297, (a) in dorsal, (b) ventral, and (c) latero-ventral views; the arrow points to the ventral ridge.

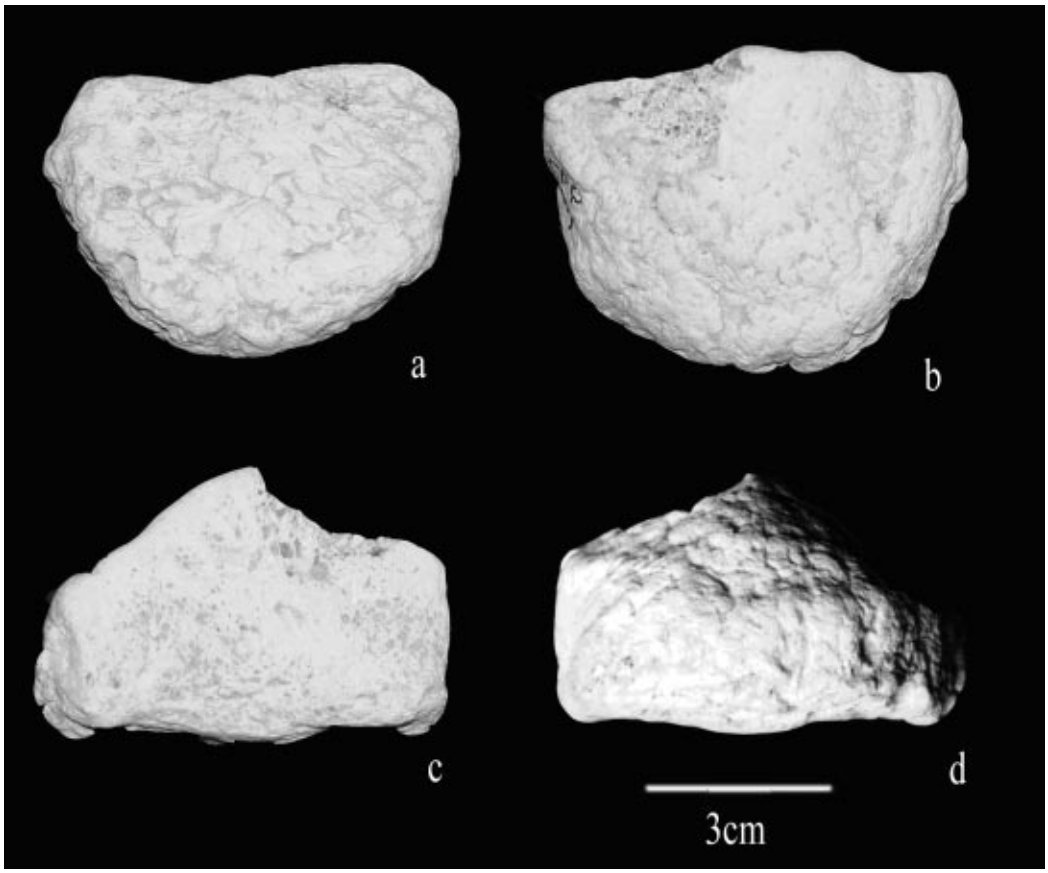

Fig. 3. CPP-674: (a) ventral view, (b) dorsal view; (c) lateral fibrous flat surface; (d) lateral round edge where some large latero-basal foramina can be evidenced.

As in *Mendozasaurus neguyelap*, (Gonzalez Riga, 2003) and the Madagascar specimens, (Dodson et al., 1998), the Brazilian osteoderms lack the cingulum that appears in some titanosaur osteoderms such as *Ampelosaurus atacis* (Le Loeuff et al., 1994).

The two osteoderms reported by Bergqvist et al. (2001) and attributed to Dinosauria indet. from the Adamantina Formation of the State of São Paulo, cannot be attributed to any dinosaur taxa due to the lateral lamellar structures observed on both by these authors.

The abundance and distribution of osteoderms on the bodies of titanosaurs are still poorly documented and unclear (Le Loeuff et al., 1994; Dodson et al.,1998). In most titanosaurs, there is no evidence for the number and positions of the osteoderms, since the descriptions were based on isolated elements. The best-known armored titanosaur is *Saltasaurus loricatus* (Bonaparte and Powell, 1980; Powell, 1980, 1992, and 2003). Numerous osteoderms were found associated with diagnostic elements of this species. In *Saltasaurus loricatus*, the osteoderms are associated with small ossicles that are not observed in CPP-297 and CPP-674.

Evidence gathered to date for *Saltasaurus loricatus* and *Mendozasaurus neguyelap* suggests that titanosaur osteoderms were distributed along the backs of animals (Bonaparte and Powell, 1980; Powell, 1980 and 1992; González Riga, 2003). In view of this evidence, we assume that the osteoderms described in this report are dorsal. For this reason, the interwoven bone pattern and foramina surface present in both CPP-297 and CPP-674, were interpreted as ventral, where the bone contacted with the dermal tissue, contradicting the interpretation of Azevedo and Kellner (1998). The structures observed at this surface were perhaps related to vascular functions and maintenance of the bone itself (Dodson et al., 1998).

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