



Masiakasaurus-like theropod teeth from the Alcântara Formation, São Luís Basin (Cenomanian), northeastern Brazil

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ARTICLE INFO

Article history:

Received 19 August 2011

Accepted in revised form 2 March 2012

Available online 29 March 2012

Keywords:

Noasauridae

Masiakasaurus

São Luís Basin

Alcântara Formation

ABSTRACT

The Alcântara Formation (Early Cenomanian, São Luís Basin) that crops out on the northern shoreline of Maranhão State, northeastern Brazil, presents a unique record of northern South American vertebrates that is similar to North African Albian–Cenomanian records. In this paper, nine theropod teeth are described. Some of these show a long, distally curved profile, laterally compressed, with a textured distal surface and a basal cross section from elliptical to subcircular. The mesial carina is deflected lingually, the distal one is deflected labially and both are gently serrated. This set of dental features is peculiar to and typical of the Malagasy genus *Masiakasaurus* from the Late Cretaceous (Maastrichtian). The Alcântara Formation material is here referred to a noasaurid related to *Masiakasaurus knopfleri* in spite of the spatial and temporal distance between them. This referral is based on the similarity of the Brazilian material with the easily distinguishable dental features of the Malagasy species. This new record should be taken into account in interpretations of the historical biogeography of noasaurids in Gondwana.

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1. Introduction

During the Early Cretaceous the continental South American margin experienced considerable diastrophism related to the intracontinental rifting that occurred during the breakup of Gondwana. As a result, several sedimentary basins were formed on the edge of the continent in the northern and northeastern Brazilian region; the São Luís Basin is one of these. The Alcântara Formation along with the Cujupe Formation represents the uppermost part of the Cretaceous succession that was deposited in these basins (Góes and Rossetti, 2001; Rossetti, 2001).

Theropods are represented in outcrops of the Early Cenomanian Alcântara Formation in the São Luís Basin by isolated teeth and fragmentary bones from the Laje do Coringa bone bed, located on Cajual Island, Alcântara municipality, Maranhão State (Price, 1947; Ferreira et al., 1992; Vilas Bôas, 1999; Medeiros et al., 2007) (Fig. 1). Among the theropod genera identified to date are some forms related to those that inhabited northwestern Africa during the Albian–Cenomanian: the tetanuran *Spinosaurus* (Medeiros and Vilas Bôas, 1999; Medeiros, 2006), *Oxalaia quilombensis* (Kellner et al., 2011), *Carcharodontosaurus*, and some remains attributed to

controversial genera or of uncertain systematic affinities that are also recorded in northern Africa (Vilas Bôas et al., 1999; Medeiros et al., 2007). Velociraptorinae dinosaurs seem to be represented in the community that lived in the north of Maranhão during the mid-Cretaceous as evidenced by their peculiar teeth (Vilas Bôas, 1999; Elias et al., 2004). Sauropod, crocodylian, pterosaur, fish, chelonian and plant remains, as well as ornithopod, sauropod and theropod ichnofossils are found in these deposits (Carvalho, 2001; Medeiros and Schultz, 2001, 2002; Elias et al., 2007; Freire et al., 2007; Medeiros et al., 2007; Pereira and Medeiros, 2008; Lindoso et al., 2011).

Dinosaur teeth are important and representative elements of continental terrestrial Mesozoic faunas (Dyke and Malakhov, 2004; Smith et al., 2005) and many authors recognize their taxonomic utility and value (Currie et al., 1990; Smith et al., 2005; D'Amore, 2009).

In this paper the teeth of a predatory dinosaur previously unknown in the northeastern South American deposits are described. The morphotypes show clear resemblance to those of the Late Cretaceous Malagasy form *Masiakasaurus knopfleri* Sampson, Carrano and Forster, 2001.

2. Geological setting and lithostratigraphy

The teeth described here come from the São Luís Basin, one of several sub-basins of a larger intracratonic sedimentary area, the

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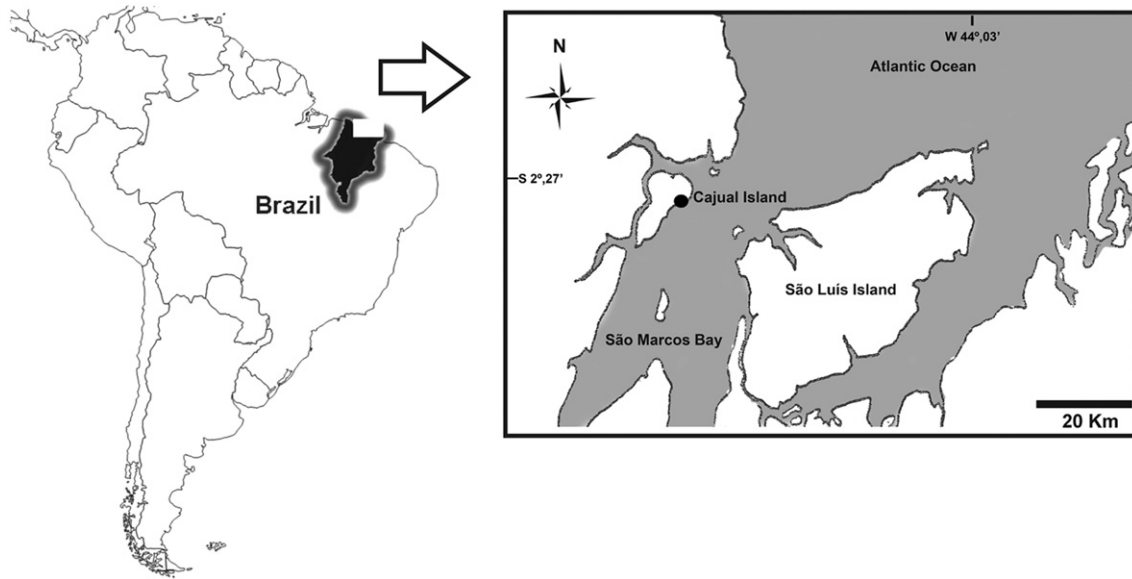


Fig. 1. Location of Cajual Island, northeastern Brazil. The black point indicates the area where the material was collected.

Parnaíba Province. It is located in the equatorial portion of Brazil and covers an area of 250.000 km² (Rossetti and Góes, 2003). It is limited by the following structural arches: the Xambioá-Alto Parnaíba Antecline to the south, the Capim Arch to the northwest, and the Rio Parnaíba Lineament to the east (Góes, 1995). Its genesis is related to the processes of continental rapture and consequent formation of

the South Atlantic rift initiated during the Late Jurassic and Early Cretaceous (Sztamari et al., 1987; Góes and Rossetti, 2001).

The sedimentary record of the São Luís Basin consists almost entirely of Cretaceous rocks that can be divided into three depositional sequences sensu Rossetti (2001): S1, S2 and S3 (Fig. 2A). The S1 sequence accumulated during the Late Aptian and Early Albian,

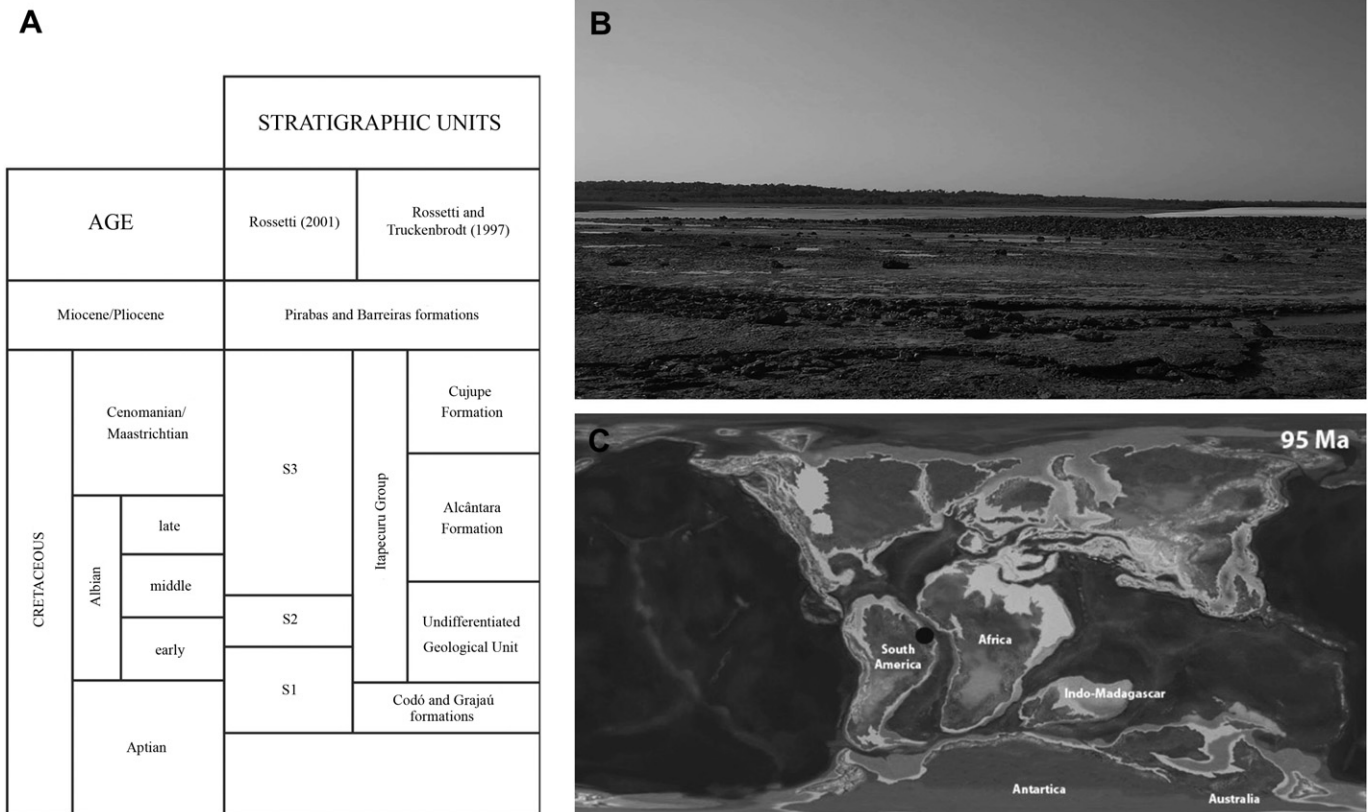


Fig. 2. Geological setting of the *Masiakasaurus*-like teeth. A, stratigraphy of the São Luís Basin sequence (modified from Rossetti, 2001). B, Laje do Coringa bone bed. C, palaeobiogeographical model of Gondwana during the Cenomanian. The black point indicates the area of discovery (modified from Blakey, 2011).

and includes about 450 m of sandstones, shales and limestones deposited in shallow marine, lacustrine and fluvio-deltaic environments that make up the Grajaú and Codó formations. The S2 sequence of Early–Middle Albian age consists of about 500 m of sandstone and pelitic deposits attributed to shallow marine and fluvio-deltaic environments that make up the Itapecuru Formation (Campbell et al., 1949) or an Undifferentiated Unit (see Rossetti and Truckenbrodt, 1997). The S3 sequence developed between the Middle Albian and the Late Cretaceous. It comprises 600–800 m of sandstones and pelitic deposits referred to the Alcântara and Cujupe formations (Rossetti and Truckenbrodt, 1997; Paz and Rossetti, 2001). Palynological studies point to a hot climate with a tendency towards aridity for the Albian–Cenomanian sequences (Pedrao et al., 1993).

The Alcântara Formation is well documented in the coastal cliffs of northern Maranhão State and contains a continental vertebrate fauna that is unique in South America in respect of several taxa (see Table 1). This Cretaceous formation in the São Luís Basin consists of a 30–35 m package of sandstones, limestones, argillites and conglomerates that accumulated in a tidal and storm-influenced estuarine environment (Mesner and Wooldridge, 1964; Klein and Ferreira, 1979; Pedrao et al., 1993; Rossetti, 1997, 2001; Holz, 2003).

Fossiliferous conglomerate levels in the formation occur on Cajual Island (Corrêa Martins, 1997) (Fig. 2B) and have been interpreted as transgressive lags (Holz, 2003). The fossils recorded from these deposits include dinosaurs, crocodylians, pterosaurs, fishes and vascular plants such as conifers and pteridophytes (see summary in Medeiros et al., 2007).

3. Systematic palaeontology

Superorder Dinosauria Owen, 1842

Order Saurischia Seeley, 1888

Suborder Theropoda Marsh, 1881

Superfamily Abelisauroidea Bonaparte and Novas, 1985

Family Noasauridae Bonaparte and Powell, 1980

Genus and species indet.

Figs. 3, 4

Material. UFMA 1.20.554 (a–i).

Type locality. Cajual Island, Alcântara municipality, Maranhão State, Brazil.

Stratigraphic horizon. Alcântara Formation, São Luís Basin, Albian–Cenomanian.

Repository. The material, consisting of nine isolated teeth of two distinguishable morphotypes, is catalogued in the palaeontological collection of the Universidade Federal do Maranhão (UFMA), São Luís city, Maranhão State as UFMA 1.20.554 (Fig. 3).

Description. The largest tooth, UFMA 1.20.554 (a), is 16 mm high from the crown base to the apex; it is distally curved with an apex that is more rounded than pointed. The cross section at the base is elliptical with a slight lateral compression. A pair of carinae bearing some gentle serration is present. The mesial carina is deflected to a lingual position whereas the distal one is deflected labially, which is different from the usual mesiodistal alignment seen in most theropods. The distal surface of the crown, located between the carinae, is highly textured. UFMA 1.20.554 (b) is 15 mm long and distally curved. This tooth is fractured in its medial portion, but preserves the slightly serrated carinae. The distal surface between the carinae is also textured, but differently from that of UFMA

Table 1

Vertebrate fauna of the Alcântara Formation. Asterisk indicates taxa occurring in northern Africa.

Chondrichthyes

Elasmobranchii

Hybodontidae

*Tribodus** sp. (Medeiros et al., 2007)

Ptychodontidae

aff. *Hylaeobatis* sp. (Medeiros, 2001)

Batoidea

Myliobatis sp. (Eugênio, 1994; Dutra and Malabarba, 2001)

Sclerorhynchidae

Atlanticopristis equatorialis (Pereira and Medeiros, 2008)

*Onchopristis numidus** (Pereira and Medeiros, 2003, 2007)

Osteichthyes

Actinopterygii

Polypteriformes

*Bartschichthys** sp. (Dutra and Malabarba, 2001; Pereira and Medeiros, 2003)

Neopterygii

Pycnodontiformes indet. (Sousa et al., 2004)

Semionotiformes

*Lepidotes** sp. (Ferreira et al., 1995; Medeiros and Schultz, 2001;

Medeiros et al., 2007)

Teleostei

*Stephanodus** sp. (Dutra and Malabarba, 2001; Pereira and Medeiros, 2003)

Sarcopterygii

Coelacanthiformes

*Mawsonia gigas** (Medeiros and Schultz, 2001; Medeiros et al., 2007;

Medeiros et al., 2011)

Dipnoi

Arganodus (= *Asiatoceratodus*) *tiguidiensis** (Castro et al., 2004)

Ceratodus brasiliensis (= *africanus*)* (Cunha and Ferreira, 1979;

Medeiros and Schultz, 2001; Medeiros et al., 2007)

Protopterus (= *Ceratodus*) *humei** (Toledo et al., 2005)

Equinoxiodus alcantarensis (Toledo et al., 2011)

Crocodyliformes

?Notosuchia

Coringasuchus anisodontis (Kellner et al., 2009)

Candidodon sp. (Santos et al., 2011)

Pterosauria

Ornithocheiroidea

Ornithocheiroidea indet. (Elias et al., 2007; Lindoso et al., 2011)

Anhangueridae indet. (Elias et al., 2007; Lindoso et al., 2011)

Dinosauria

Dinosauria incertae sedis

"*Sigilmassasaurus brevicollis*"* (Medeiros and Schultz, 2001, 2002;

Medeiros et al., 2007)

Saurischia

Sauropoda

Diplodocoidea

cf. *Rayosaurus* (= *Limaysaurus*) (Medeiros and Schultz, 2004;

Medeiros et al., 2007)

Titanosauriformes

Titanosauria indet. (Medeiros and Schultz, 2001, 2002;

Medeiros et al., 2007; Lindoso et al., 2009)

Andesauridae indet. (Medeiros and Schultz, 2001, 2002;

Medeiros et al., 2007)

?*Malawisaurus** (Freire et al., 2007)

Theropoda

aff. "*Elaphrosaurus iguidiensis*"* (Medeiros et al., 2007)

? cf. *Bahariasaurus ingens** (Medeiros and Schultz, 2001, 2002;

Medeiros et al., 2007)

Spinosauridae

Oxalaia quilombensis (Kellner et al., 2011)

*Spinosaurus** sp. (Medeiros and Vilas Bôas, 1999; Medeiros

and Schultz, 2001, 2002; Medeiros, 2006; Medeiros et al., 2007)

Carcharodontosauridae

*Carcharodontosaurus** sp. (Vilas Bôas et al., 1999; Medeiros

and Schultz, 2001, 2002; Medeiros et al., 2007)

Velociraptorinae indet. (Elias et al., 2004; Elias, 2006)

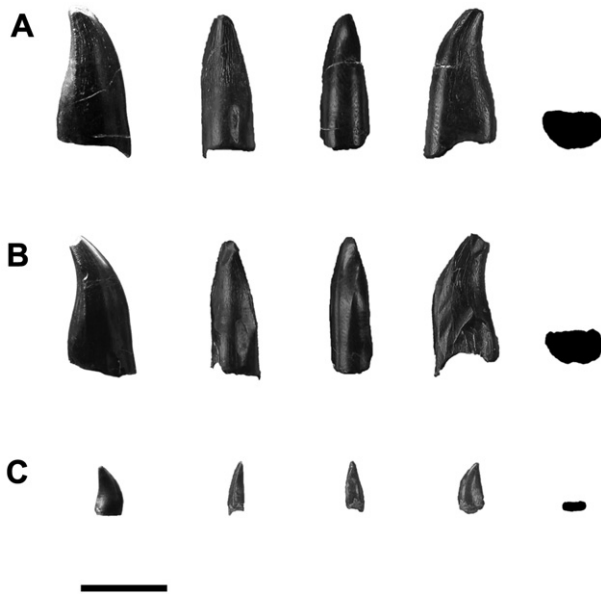


Fig. 3. A–C, *Masiakasaurus*-like theropod teeth (UFMA 1.20.554) in, from left to right, labial, distal, mesial, lingual and basal cross section views. Scale bar represents 1 cm.

1.20.554 (a); the cross section at the base of the crown of both UFMA 1.20.554 (a) and (b) is subcircular. Denticles can be observed along the whole length of the carina of UFMA 1.20.554 (a) with a density of 5 per 1 mm. Morphologically the denticles are homogeneous in size and shape, being distally rounded (Fig. 4).

A second morphotype is represented by UFMA 1.20.554 (c). It is 6 mm high and labiolingually compressed. It is slightly curved distally, with a mesial carina extending from the base of the crown up to a point about two-thirds of the height of the tooth and with no visible serrations; the distal carina is slightly serrated and extends over the entire height. On the distal carina a density of 7 denticles per 1 mm is observed. The lozenge-shaped denticles are homogeneous in shape and size (Fig. 4); the cross section of the crown is elliptical. The carinae in this morphotype are aligned mesiodistally along the major axis of the tooth.

4. Discussion

Theropod teeth are abundant in the fossil record and broadly used at distinct levels of taxonomic classification (e.g., Currie et al., 1990; Smith et al., 2005; D'Amore, 2009). In Brazil, they are the most representative elements in Cretaceous deposits (Kellner, 1996; Vilas Bôas, 1999; Kellner and Campos, 2000; Elias et al., 2004; Medeiros, 2006; Medeiros et al., 2007).

Teeth collected from the conglomeratic deposits of Laje do Coringa (Fig. 2B), exhibit a morphology that is remarkably similar to

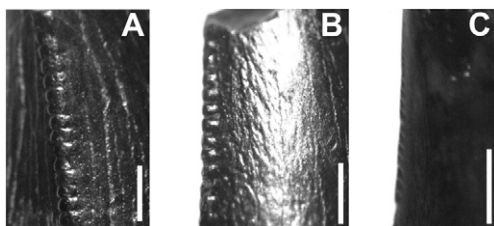


Fig. 4. Details of *Masiakasaurus*-like teeth serrated carinae. A, UFMA 1.20.554 (a), labial carina. B, UFMA 1.20.554 (b), labial carina. C, UFMA 1.20.554 (c), distal carina. Scale bar represents 1 mm.

that of *Masiakasaurus knopfleri* teeth from Late Cretaceous (Maastichtian) deposits in the Mahajanga Basin of northwestern Madagascar. UFMA 1.20.554 (a) and (b) are identical to the anterior dentary teeth of *Masiakasaurus* in being elongated and distally curved, with a pair of faintly serrated carinae positioned lingually and labially. UFMA 1.20.554 (c) represents a second morphotype that is more compressed labiolingually, with a pair of carinae that are mesiodistally aligned. The mesial carina does not exhibit serrations (however, the possibility that the serration might have been erased by abrasion cannot be ruled out) and its length barely extends to the middle of the crown of UFMA 1.20.554; the carina is finely serrated and extends up to the apex. These features are also observed on the distal dentary and maxillary teeth of *Masiakasaurus* (see Carrano et al., 2002; Fig. 3A). The teeth described here are considered to belong to an undetermined species and genus of Noosauridae.

The Abelisauroida occur in South America, India, Madagascar, Africa and Europe (von Huene and Matley, 1933; Bonaparte and Powell, 1980; Bonaparte, 1986, 1991; Buffet et al., 1988; Astibia et al., 1990; Accarie et al., 1995; Sereno et al., 2004; Novas, 2007) and includes the clades Abelisauridae and Noosauridae (Fig. 5). In Brazil, only one taxon has been described: *Pycnonemosaurus nevesi* (Kellner and Campos, 2002, from the Late Cretaceous Bauru Group (Kellner and Campos, 2002). Sparse occurrences based on teeth and premaxillary fragments were also reported by Bertini (1996), Candeiro (2002) and Candeiro et al. (2004). The teeth reported here record the occurrence of a noosaurid in the Cenomanian of northeastern Brazil, revealing that this group had reached northeastern South America by this time. Currently *Masiakasaurus knopfleri* is the best known noosaurid. The fragmentary condition of other records attributed to the clade makes it difficult to undertake satisfactory comparisons (Carrano et al., 2011). The referral of the Brazilian specimens to Noosauridae is sustained on the basis of the very distinct dental morphology seen in *Masiakasaurus*, thus far shared only with the material described here. The Brazilian form is significantly larger than the Malagasy species (Carrano, pers. comm. 2007; Sertich, pers. comm. 2010). The record of a noosaurid related to *Masiakasaurus* in northern South America suggests that a taxon including *Masiakasaurus* (or its ancestor) and closely related forms first appeared during the Early Cretaceous.

The community that inhabited northeastern South America during the Cenomanian is more similar to that recorded from northern Africa than to that from austral South America, as suggested by the presence of the theropods *Spinosaurus*,

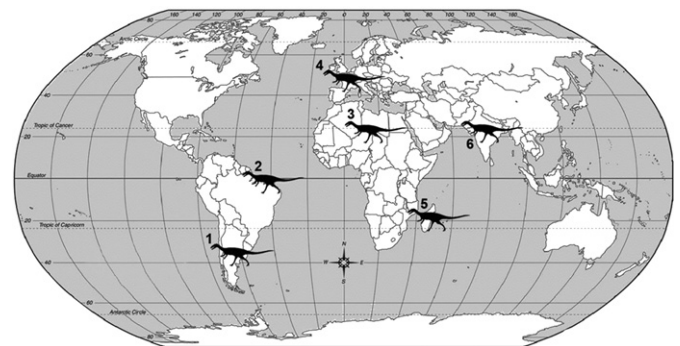


Fig. 5. Overall record of Noosauridae: 1, Argentina, *Velocisaurus unicus* (Santonian, Bajo de La Carpa Formation) and *Noosaurus leali* (Maastichtiano, Lecho Formation); 2, Brazil, Noosauridae indet. (Cenomanian, Alcântara Formation); 3, Niger, Noosauridae indet. (Aptian–Albian, Gadoufaoua); 4, France, *Genusaurus sisteronis* (Albian, Sisteron); 5, Madagascar, *Masiakasaurus knopfleri* (Maastichtiano, Maevarano Formation); 6, India, *Laevisuchus indicus*, *Composuchus solus*, *Ormithomimoides? barasilensis*, *Jubbulpuria tenuis* (Maastichtian, Lameta Formation).

Carcharodontosaurus, “*Sigilmassasaurus*”, and several other taxa reported from the Alcântara Formation but yet to be conclusively identified in both continents (Medeiros and Schultz, 2002; Medeiros et al., 2007; see also Candeiro et al., 2011). At the beginning of the Late Cretaceous, South America and Africa were putatively already separated (see Scotese, 2007; Blakey, 2011) (Fig. 2C) and the Atlantic Ocean would have represented a significant barrier between the faunas of northeastern Brazil and northern Africa. A hypothesis that has been suggested for the maintenance of the faunal flux between these divergent landmasses is a subaerial connection by volcanic islands (see Cox, 1980). The complex scenario recovered from the Cajual Island deposits may well fit this interpretation (Medeiros et al., 2007), although the faunal similarities in relation to the African record may also be attributed to morphological conservatism after the major vicariance event that separated these southern continents. Information useful for palaeobiogeographical reconstruction of groups such as noosaurids during the history of Gondwana is still scattered and interpretations based on them are inconclusive.

Acknowledgements

We thank Matthew Carrano (National Museum of Natural History, Smithsonian Institution, New York), Joseph Sertich and David Krause (Stony Brook University, New York), Círio L. Caudas dos Santos, Jorge Luís Moraes (Departamento de Entomologia e Vetores da Universidade Federal do Maranhão), Ronny Anderson B. Santos (Universidade Federal do Maranhão) and Ralph Molnar (Museum of Northern Arizona), for their valuable revision and critical evaluation of the manuscript. The work for this paper received financial support from the Secretaria de Cultura do Maranhão, Coordenação de Aperfeiçoamento de Nível Superior (CAPES) and the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ).

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