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CRETACEOUS RESEARCH

Amazonsaurus maranhensis gen. et sp. nov. (Sauropoda, Diplodocoidea) from the Lower Cretaceous (Aptian–Albian) of Brazil

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Abstract

A new genus and species of an Aptian–Albian sauropod from the Itapecuru Formation, northern Brazil, *Amazonsaurus maranhensis*, is described. It is known from an incomplete, but diagnostic postcranial skeleton. The new taxon possesses several autapomorphies, such as the anterior caudal vertebrae with lateral laminae formed by the coalescence of the spinoprezygapophyseal and postzygodiapophyseal laminae and, to a lesser extent, of the postzygodiapophyseal laminae. It exhibits many synapomorphies supporting its inclusion in the Diplodocoidea. These include high caudal neural arches and anterior caudal neural arches with spinoprezygapophyseal laminae on the lateral aspect of the neural spine. This record is consistent with previous hypotheses on the existence of a community of Afro-South American dinosaurs.

Keywords: Sauropoda; Diplodocoidea; Itapecuru Formation; Early Cretaceous; Brazil

1. Introduction

The sauropods from the Brazilian Cretaceous basins have generally been attributed to the Titanosauridae (Santucci and Bertini, 2001). Titanosaurids are commonly found in the Late Cretaceous formations of the Bauru Basin. The occurrence of non-titanosaurid sauropods is restricted to the basal diplodocoid *Rebbachisaurus* sp. from the São Luís Basin (Cenomanian, northern Brazil; Medeiros, 2001).

The material described herein was found in Aptian–Albian strata of the Itapecuru Formation, Parnaíba Basin, Maranhão State, northern Brazil (Fig. 1). This region is situated on the eastern limits of the Brazilian Legal Amazon. Formerly, the only dinosaur specimens reported from the Brazilian Amazon were a theropod tooth from the Alter do Chão Formation, Amazonas Basin (Price, 1960) and bone fragments from the São Luís Basin (Price, 1947; Ferreira et al., 1992; Medeiros, 2001; Medeiros and Schultz, 2001).

Currently, Gondwanan Lower–mid Cretaceous sauropods represent three clades: a lineage of basal eusauropods represented by *Jobaria tiguidensis*; the Titanosauriformes; and the Diplodocoidea.

In this contribution we describe and discuss a new diplodocoid genus, based on a single species, which is the first record of a sauropod dinosaur from the Brazilian Lower Cretaceous.

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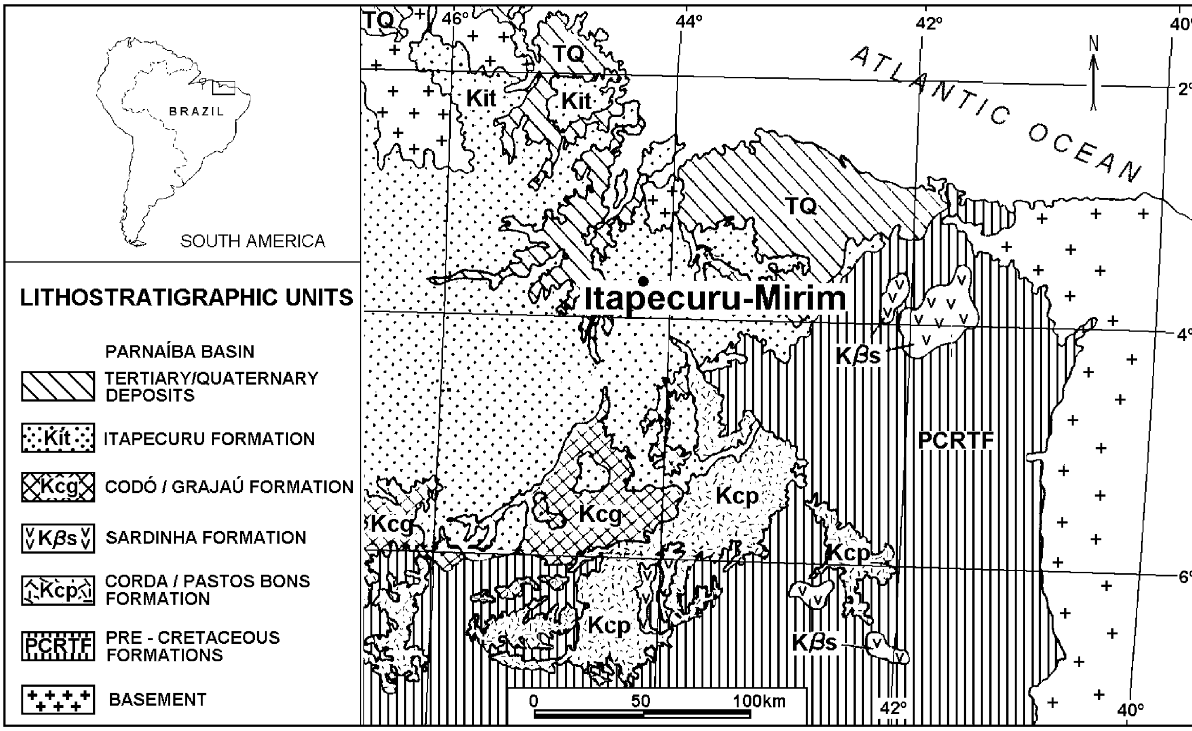

Fig. 1. Location and geological maps of the Parnaíba Basin. *Amazosaurus maranhensis* gen. et sp. nov. was recovered from Itapeucuru County, Maranhão State, Brazil (modified from Cassab et al., 1994).

2. Geological setting and lithostratigraphy

The new sauropod comes from the intracratonic Parnaíba Basin. This basin has a total area of 600,000 km^2 and occupies a large portion of northeastern Brazil. The deposits comprise Palaeozoic and Mesozoic sedimentary sequences. Rossetti et al. (2001) redefined the spatial distribution of the Parnaíba Basin, and considered the portion which includes the type locality of the fossil described herein as a new basin, the Grajaú Basin.

The Cretaceous sequence of the Parnaíba Basin (or Grajaú Basin *sensu* Rossetti et al., 2001) comprises continental and nearshore deposits. The oldest unit is the Pastos Bons Formation, mainly consisting of clastic material. It is overlain by conglomerates and red cross-bedded sandstones designated as the Corda Formation. These are commonly interpreted as sediments of fluvial-aeolian environments deposited in a semi-arid climate. During the opening of the Equatorial Atlantic margin, extensive basalt flows (Sardinha Formation) overlaid these units. Later, during the Aptian–Albian, conglomerates, coarse to fine sandstones (Grajaú Formation), shales and carbonates (Codó Formation) were deposited. The depositional setting of the latter deposits were fluvial and marine environments. The climate at this time was hot and dry (Pedrão et al., 1993). The fine-grained sandstones with interbedded argillaceous and carbonate levels, the Itapecuru Formation, is the youngest Cretaceous unit (Aptian–Albian). The depositional environment is considered to have been marine in the northern portion, changing to lacustrine and floodplain in the southern part of the basin.

The sauropod specimen was found in the Itapecuru Formation, 2 km south of the type-section of this lithostratigraphic unit at the Mata locality (Itapecuru-Mirim County, State of Maranhão, Brazil). There are two lithofacies in the Mata sedimentary succession, named L2 and L3 (Fig. 2). The L2 lithofacies are finely laminated reddish siltstones; some levels contain fluidization structures and invertebrate ichnofossils. There are fossils of non-marine molluscs (Bivalvia), turtles and scales of freshwater fishes. The reddish siltstones are interbedded with fine sandstones in which climbing ripples are observed. The layers display lenticular to tabular geometry, and carbonate levels occur in their upper portion. The L3 lithofacies are fine to medium grained sandstones with channel cross-stratification, climbing ripples and sigmoidal structures. The layers display a lenticular to tabular geometry, with thicknesses varying from 0.5 to 3.0 m, and palaeocurrents trending southwest. In a vertical profile, the muddy facies grade up into sandy deposits in a clear coarsening upward pattern. This coarsening upward cycle at Mata is part of a sequence 3 m thick that is interpreted as a fluvio-deltaic

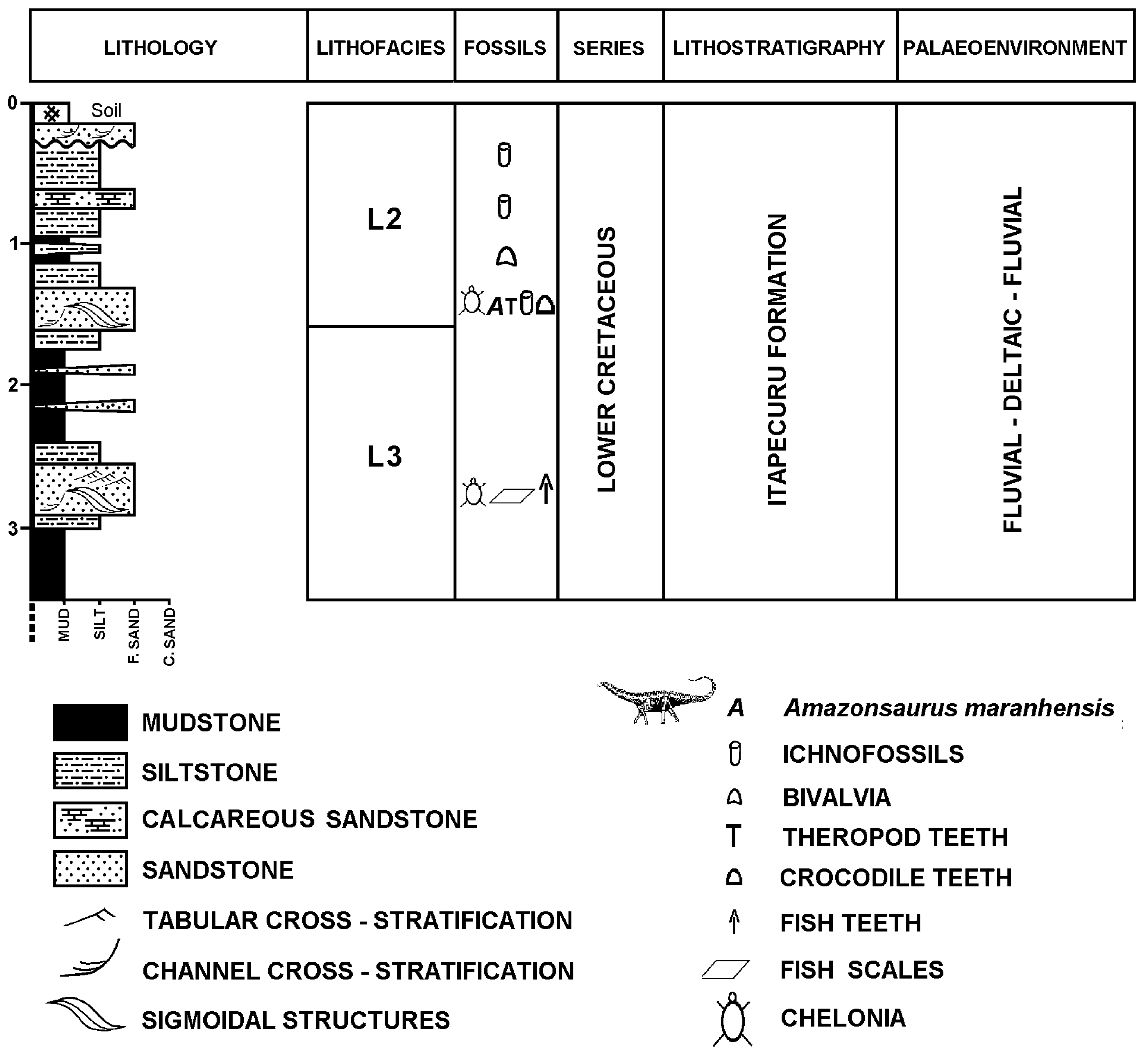

Fig. 2. Lithologies and Lithofacies at Mata, Itapecuru-Mirim County, Maranhão State and the fossiliferous strata.

progradation in lacustrine conditions during Aptian–Albian times (Gonçalves and Carvalho, 1996). The new sauropod specimen occurs in the L2 lithofacies (Fig. 3), which are interpreted as proximal fluvial mouthbar deposits, whereas the subjacent L3 lithofacies represent the distal deposits of these mouthbars (delta front).

3. Systematic palaeontology

Order Saurischia Seeley, 1887
Suborder Sauropoda Marsh, 1878
Superfamily Diplodocoidea (Marsh, 1884) *sensu* Upchurch, 1995

Family indet.
Amazonsaurus gen. nov.

Type-species. *Amazonsaurus maranhensis* sp. nov.

Derivation of name. For the type-locality which is part of the Brazilian Legal Amazon region, plus *sauros*, Greek for lizard, reptile.

Diagnosis. Small sauropod characterized by caudal neural spines that are straight and posteriorly inclined, with 'lateral' laminae formed by the spinoprezygapophyseal and postzygodiapophyseal laminae which, at least in the most anterior ones, bend anteriorly in such a way that the anterior surface of the lamina is concave while the posterior surface is convex.

Amazonsaurus maranhensis sp. nov.
Fig. 4

Derivation of specific name. From the Brazilian state of Maranhão.

Holotype. Two dorsal neural spines (MN 4558-V; UFRJ-DG 58-R/9); two dorsal centra (MN 4559-V; MN

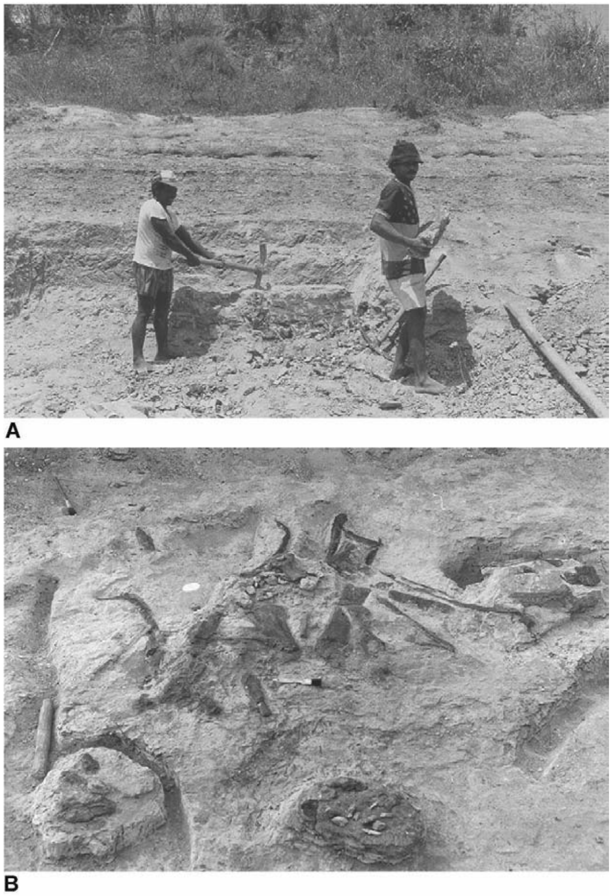

Fig. 3. Excavation area at Mata, Itapecuru-Mirim County (A). The sauropod comes from a calcareous sandstone level (Itapecuru Formation, Aptian–Albian) and is associated with freshwater molluscs and turtles (B).

s/n°-V); neural spine of anterior caudal vertebra (UFRJ-DG 58-R/7); one mid caudal vertebra (MN 4555-V); one mid-posterior caudal vertebra (MN 4560-V); one posterior caudal vertebra (MN 4556-V); one posterior caudal vertebra (UFRJ-DG 58- R/10); four chevrons (UFRJ-DG 58-R/2; 58-R/3; 58-R/4; 58-R/5); four chevrons (MN 4564-V); an ilium (UFRJ-DG 58-R/1); a partial pubis (MN s/n°-V); and three ribs (MN 4562-V).

Type locality. Mata, Itapecuru-Mirim County, Maranhão State, Brazil.

Stratigraphic horizon. Itapecuru Formation, Parnaíba Basin. Lower Cretaceous (Aptian–Albian).

Repository. UFRJ-DG, Universidade Federal do Rio de Janeiro, Departamento de Geologia, Brazil; MN-V, Universidade Federal do Rio de Janeiro, Museu Nacional, Departamento de Geologia e Paleontologia, Coleção de Paleovertebrados, Brazil.

3.1. Description

Dorsal vertebrae. There are two slightly opisthocoelic centra (MN 4559-V; MN s/n°-V) (Fig. 5). These are very wide and low. Their ventral surfaces are flattened, giving the centra a squared aspect. The pleurocoels are deep, extending from the anterior to the posterior borders of the centra, occupying almost its total internal area. This fact, coupled with the laminar constitution of the neural arches, gives the vertebrae a fragile architecture.

There is a badly crushed dorsal neural arch (UFRJ-DG 58-R/9) (Fig. 6), which preserves both prezygapophyses, the bases of the diapophyses, the posterior centrodiapophyseal lamina (PCDL) and the base of the centropostzygapophyseal lamina, which as in other diplodocoids, is nearly confluent with the PCDL. The prespinal lamina is axially developed, resembling that of the MN 4558-V (Fig. 7). The base of the spinodiapophyseal lamina is observed, both in UFRJ-DG 58-R/9 and MN 4558-V.

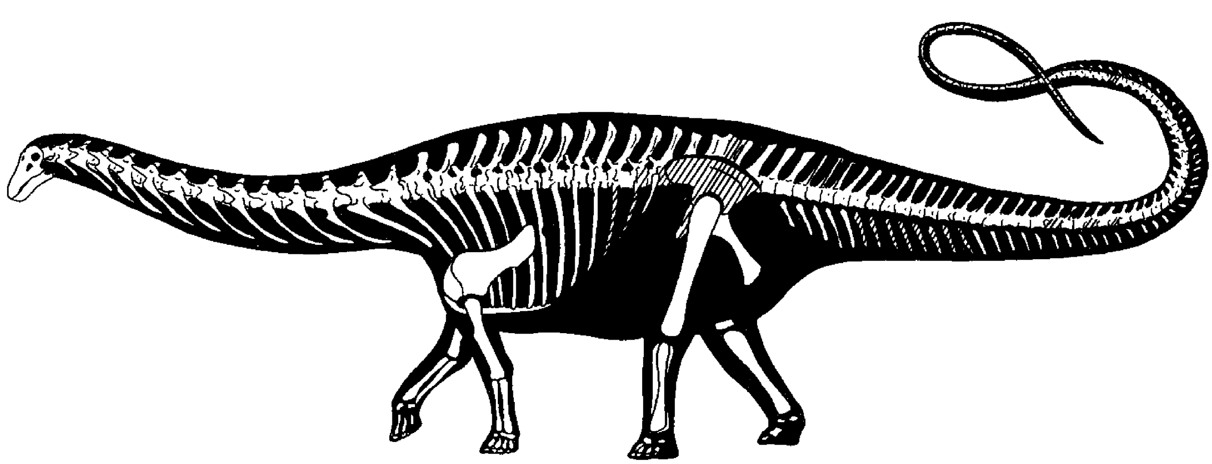

Fig. 4. Diagramatic reconstruction of *Amazonsaurus maranhensis* gen. et sp. nov., indicating the preserved osteological elements (oblique parallel lines) (Art by Ariel Milani Martine).

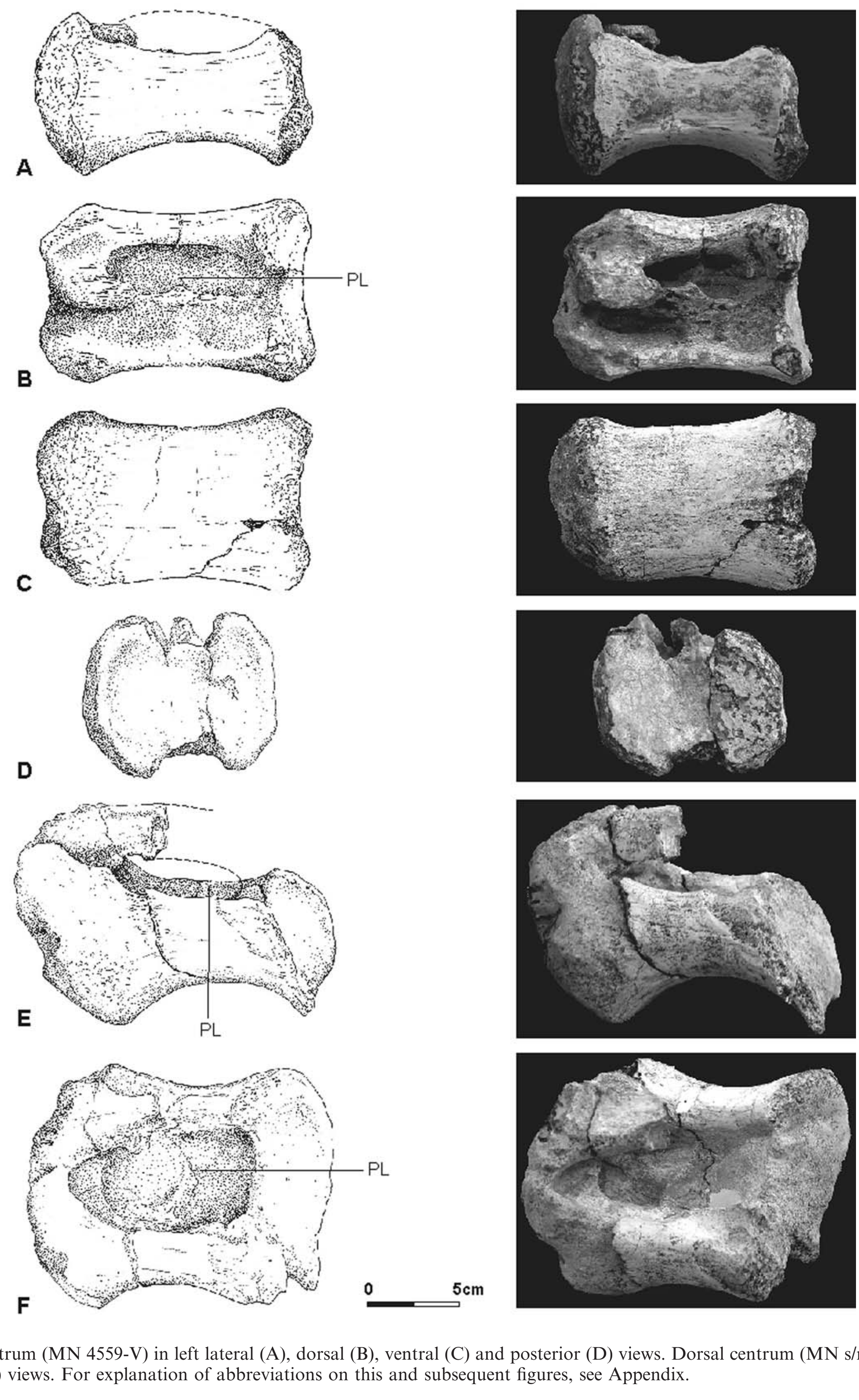

Fig. 5. Dorsal centrum (MN 4559-V) in left lateral (A), dorsal (B), ventral (C) and posterior (D) views. Dorsal centrum (MN s/n°-V) in left lateral (E) and dorsal (F) views. For explanation of abbreviations on this and subsequent figures, see Appendix.

Sacral vertebrae. Several fragments of sacral ribs are present, but are too fragmentary to offer any useful information.

Caudal vertebrae. A series of four anterior caudal neural arches and four complete vertebrae from the distal two-thirds of the tail have been preserved. There is

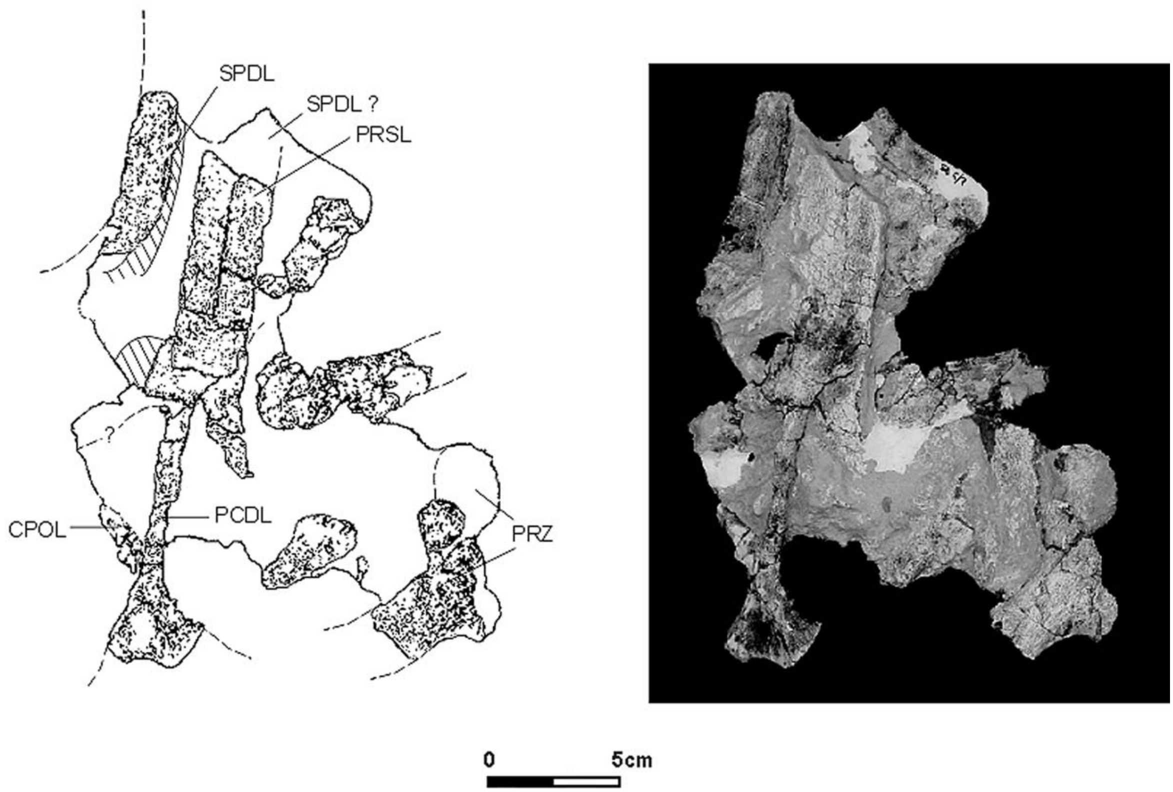

Fig. 6. Dorsal neural arch (UFRJ-DG 58-R/9) in lateral view.

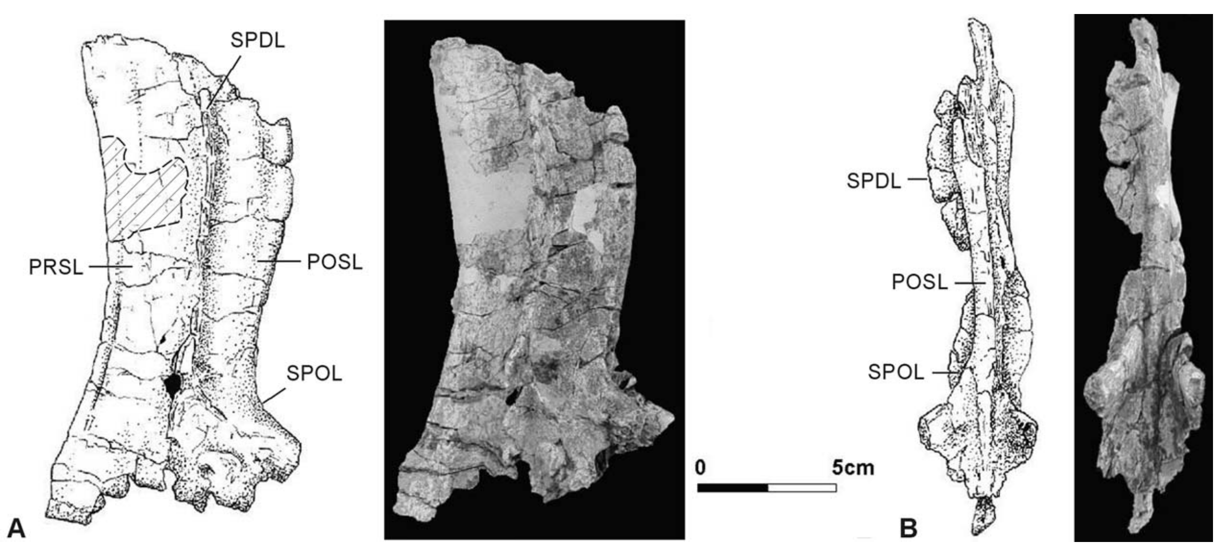

Fig. 7. Dorsal neural spine (MN 4558-V) in lateral (A) and posterior (B) views.

a complete anterior caudal neural arch (Fig. 8), which is lightly built and bears a very high neural spine with well-developed lateral, pre- and postspinal laminae (UFRJ-DG 58-R/7). Although it is lacking the centrum, the spine is set at an angle of 45 degrees with respect to the neural canal axis (Fig. 8F). The articular facets of the prezygapophyses are nearly parallel to the axial plane, whereas the neural canal opens just below the level of the prezygapophyses. The base of neural spine displays large anterolateral concavities, which are bordered by the prezygodiapophyseal (PRDL), the postzygodiapophyseal (PODL) and the spinoprezygapophyseal (SPRL) laminae (see Wilson, 1999). The SPRL are notably developed, forming most of the 'lateral' lamina

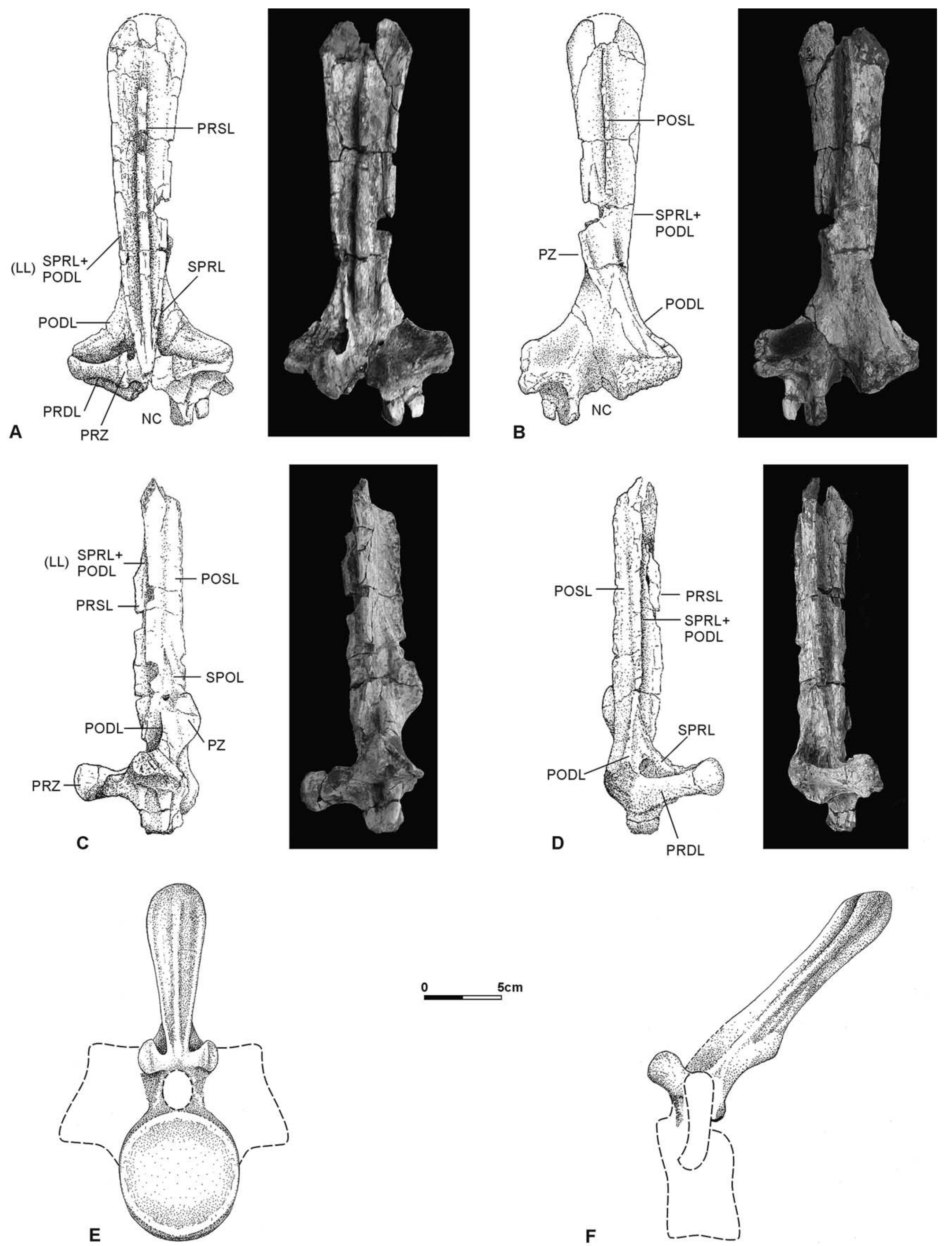

Fig. 8. Anterior caudal neural spine (UFRJ-DG 58-R/7), in anterior (A), posterior (B), left lateral (C) and right lateral (D) views. Reconstruction of the complete vertebra in anterior (E) and lateral (F) views.

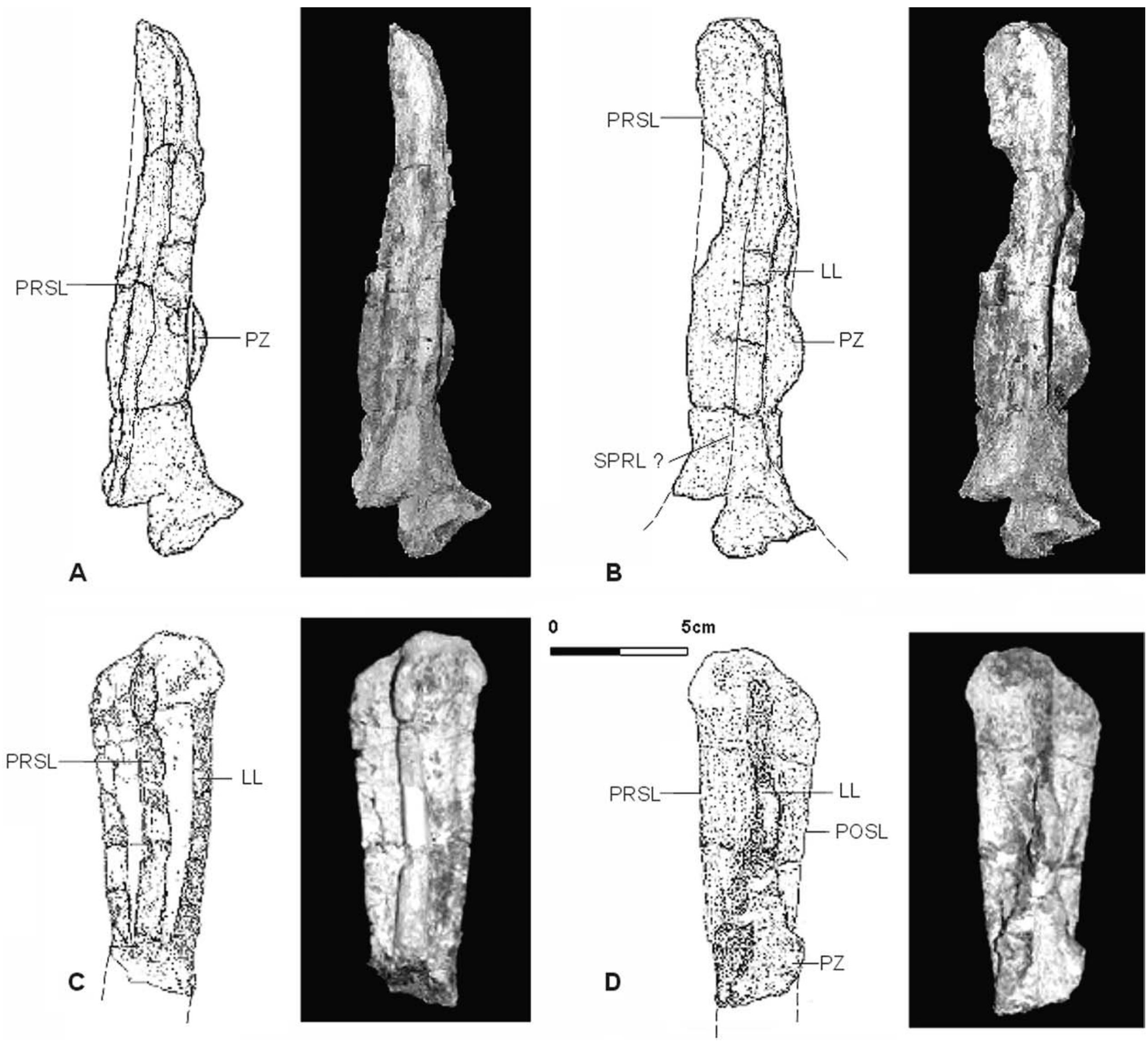

Fig. 9. Anterior caudal neural spine (UFRJ-DG 58-R/8a) in anterolateral (A) and lateral (B) views. Anterior caudal neural spine (UFRJ-DG 58-R/8b) in anterior (C) and lateral (D) views.

(LL). The PODL fails to reach the postzygapophyses. Instead, these seem to join the SPRL to participate in the 'lateral' laminae (LL). Unlike *Rebbachisaurus tessonei* (Calvo and Salgado, 1995), the 'lateral' laminae (SPRL+PODL) are posteriorly convex and anteriorly concave, which results from the anterior bending of these laminae. The spinopostzygapophyseal (SPOL), which is weakly developed, appears to join the 'lateral' lamina posteriorly.

Other elements are here interpreted as anterior caudal neural spines (UFRJ-DG 58-R/8; MN s/n°) (Fig. 9). The spine UFRJ-DG 58-R/8a (Fig. 9A, B) is lower than UFRJ-DG 58-R/7, but the SPRL and PODL are less developed and only observed as 'lateral' laminae (without differentiation of SPRL and PODL as in the previous vertebra). In MN s/n° and in UFRJ-DG 58-R/8b (Fig. 9C, D), the 'lateral' laminae are of the same pattern.

In caudal vertebra MN 4555-V (Fig. 10) the SPRL are indistinguishable, but the pre- and postspinal laminae are well developed. In the vertebra MN 4560-V (Fig. 11), the neural spine is laterally compressed and lacks any indication of 'lateral' laminae.

Only the centra are preserved in MN-4555-V (Fig. 10), MN 4560-V (Fig. 11), UFRJ-DG 58-R/10 (Fig. 12) and MN 4556-V (Fig. 13). These are invariably amphyplatyan and bear the neural arch approximately at the middle of the centrum. The series MN 4555-V, MN 4560-V and UFRJ-DG 58-R/10 shows a progressive lengthening and dorso-ventral flattening of the centra. The lateral sides of the centra are anteroposteriorly concave and the ventral

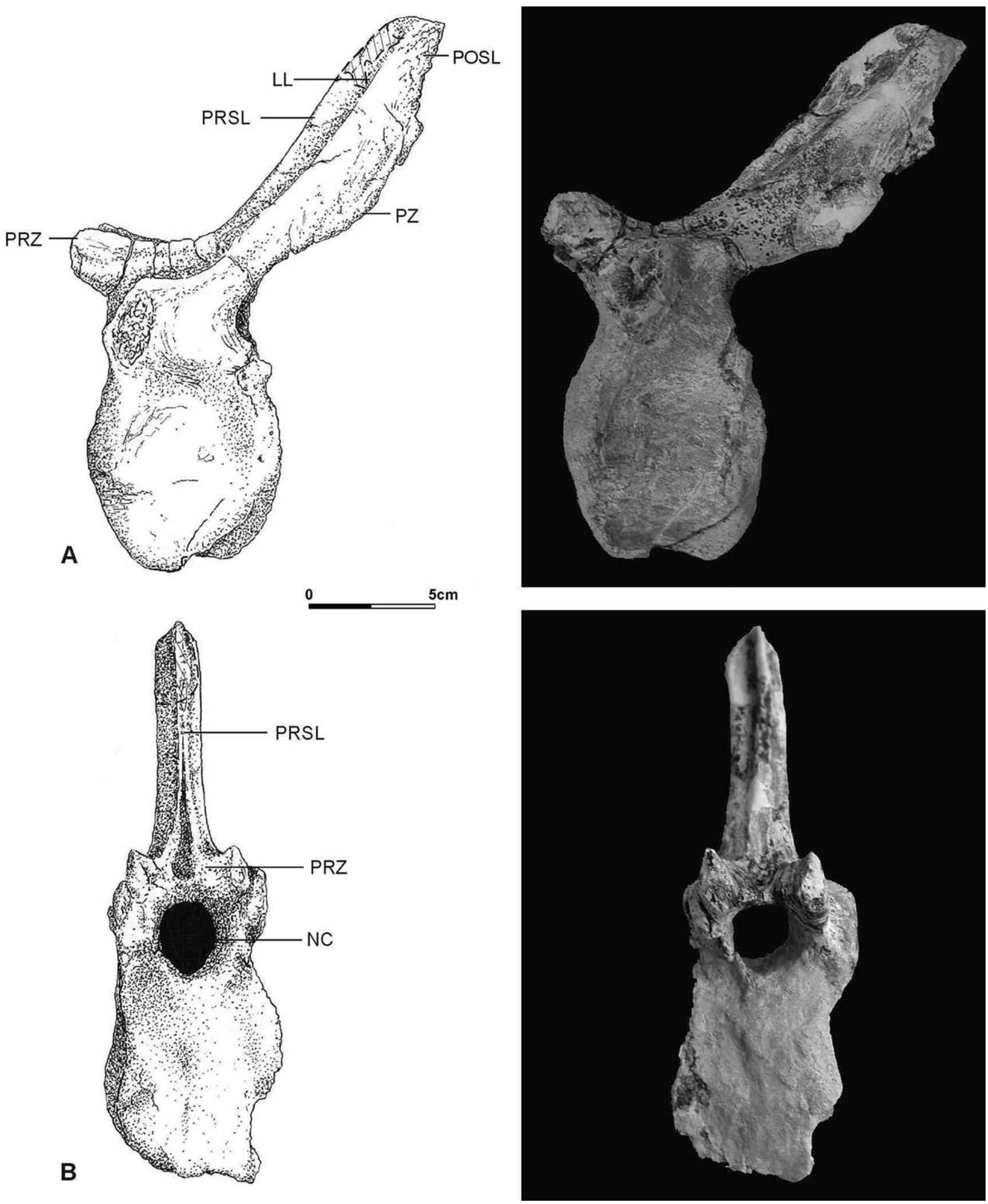

Fig. 10. Mid caudal vertebra (MN 4555-V) in left lateral (A) and anterior (B) views.

surface, at least in MN 4560-V and UFRJ-DG 58-R/10, is flat.

The posterior caudal UFRJ-DG 58-R/10 (Fig. 12) has the neural spine posteriorly directed and, as in MN 4560-V, there is no indication of transverse processes. The prezygapophyses are broken in UFRJ-DG 58-R/10, and probably extended anteriorly beyond the anterior border of the centrum. In this vertebra, the neural spine is laterally developed resulting from the separation of the postzygapophyses. The prespinal lamina is poorly developed, and has its proximal origin on the base of the articular facets of prezygapophyses.

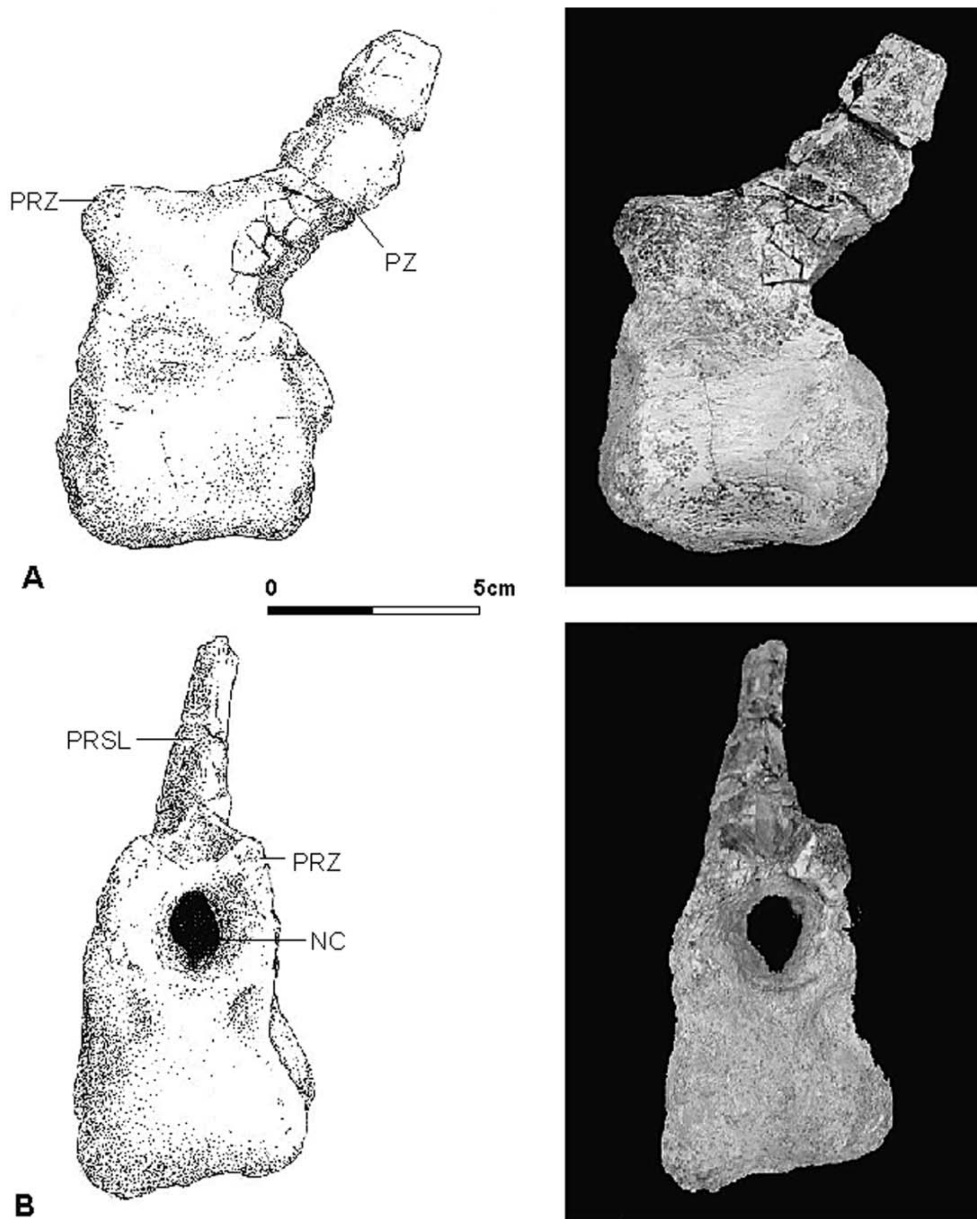

Fig. 11. Mid-posterior caudal vertebrae (MN 4560-V) in left lateral (A) and anterior (B) views.

Chevrons (UFRJ-DG 58-R/2; 58-R/3; 58-R/4; 58 R/5; MN 4564-V). Eight chevrons are preserved. All are characterized by the opening of the haemal canal and a relatively long, laterally compressed shaft (Fig. 14).

Ribs (MN 4562-V). There are three partial dorsal ribs. Two of them have preserved heads, which indicate a dicephalous condition. The capitulum is large and situated at a right-angle to the rib shaft. The tuberculum projects beyond the dorsal margin of the capitulum. The rib shaft ranges from a proximal curved cylindrical structure to a distally flattened bone (Fig. 15).

Pubis (MN s/n°- V). The pubis is represented by the proximal and mid portions. The iliac peduncle is a broad, paddle-like structure. A large obturator foramen is present, but the acetabular surface is missing (Fig. 16).

Ilium (UFRJ-DG 58-R/1). Only the left ilium is preserved; it is wide and high, and lacks the ischial peduncle and postacetabular blade (Fig. 17). The ventral border behind the semicircular acetabulum is slightly convex, forming a very long postacetabular lamina, but it is partially broken. The pubic peduncle is wider mediolaterally than anteroposteriorly as is usual among

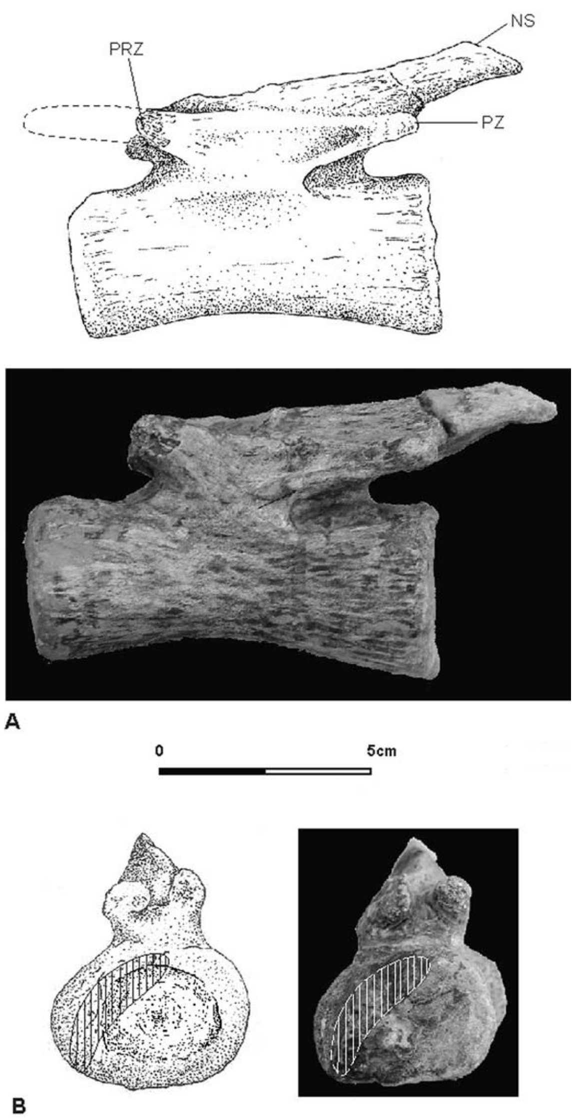

Fig. 12. Posterior caudal vertebra (UFRJ-DG 58-R/10) in left lateral (A) and anterior (B) views.

sauropods. The anterior corner of the ilium is directed upward and forward. As the ischial peduncle is missing, it allows us to observe the internal structure of this region, which bears a pneumatic cavity that may be unique among sauropods.

4. Discussion

The neural spines of the anterior caudal vertebrae of *Amazonsaurus maranhensis* are characterized by the presence of four osseous laminae: two 'lateral' (LL), and the pre- (PRSL) and postspinal (POSL). The 'lateral' laminae (LL) of the anterior caudal vertebrae result from the coalescence of the spinoprezygapophyseal (SPRL) and postzygodiapophyseal (PODL) laminae. In other diplodocoids, in contrast, the 'lateral' laminae

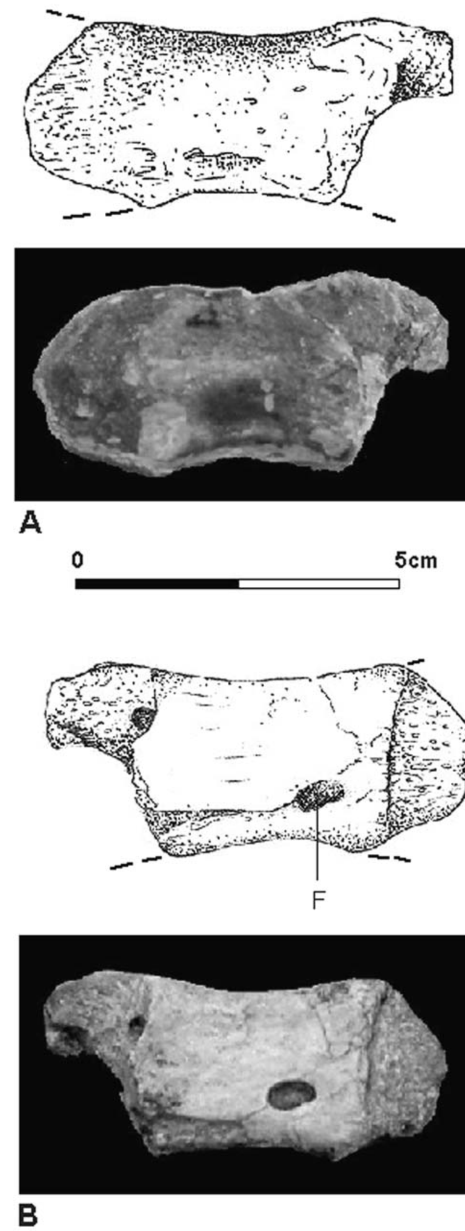

Fig. 13. Posterior caudal vertebra (MN 4556-V) in left lateral (A) and ventral (B) views.

seem to be continuous with the spinopostzygapophyseal laminae (Fig. 18B). We provisionally interpret the condition in *Amazonsaurus maranhensis* as an autapomorphy. Wilson (2002), p. 270) stated that 'anterior caudal neural arches with spinoprezygapophyseal lamina (SPRL) on lateral aspect of neural spine' is a synapomorphy of Diplodocidae plus Dicraeosauridae. However, owing to the fact that this condition seems to be present in the holotype of *Rebbachisaurus tessonei*, it is probably a synapomorphy of a larger group, perhaps the Diplodocoidea. On the other hand, in *A. maranhensis*, the thickness of the 'lateral' laminae is basically constant from the base to the top of the spine. In

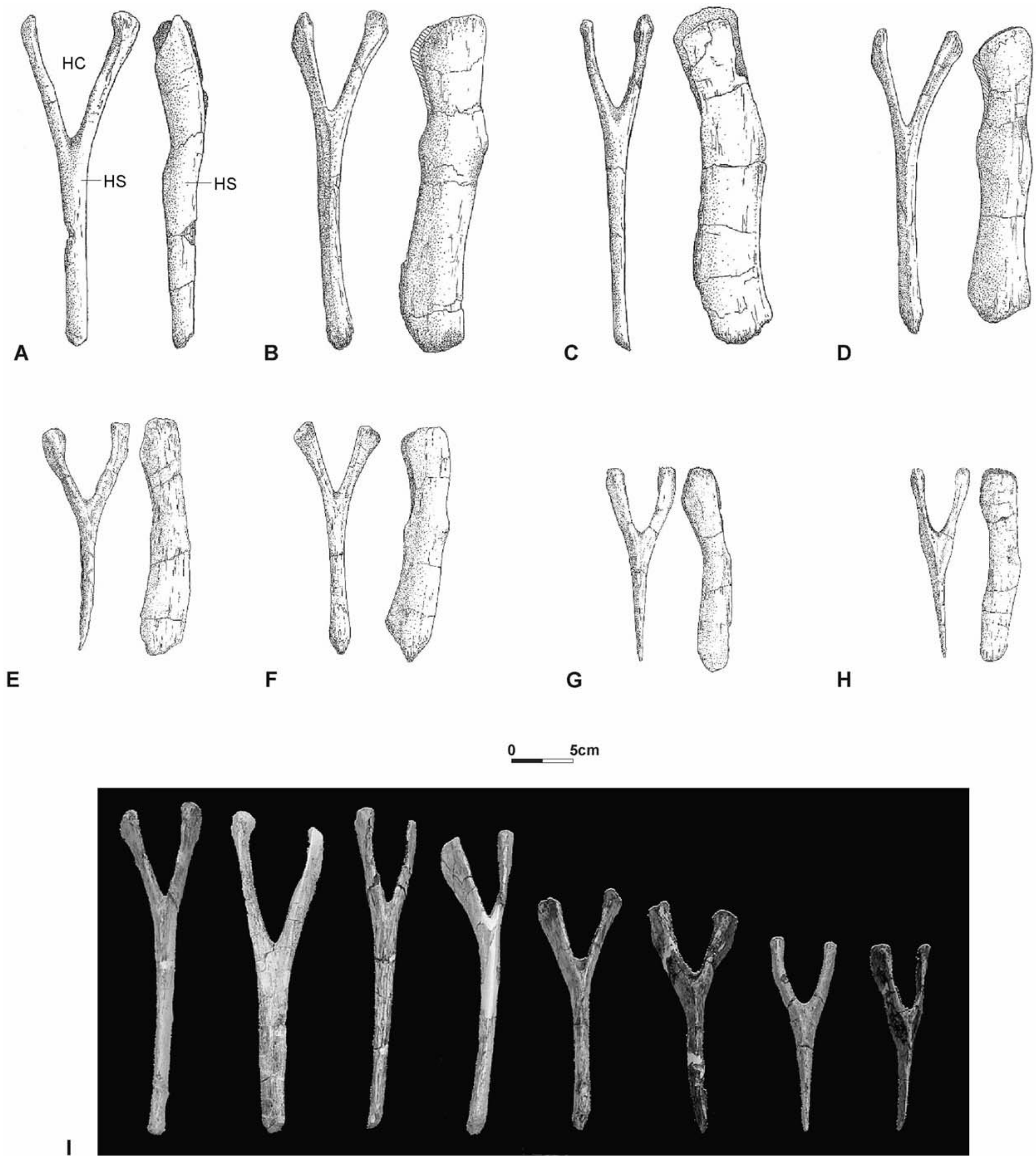

Fig. 14. Chevrons in anterior and lateral views. A, UFRJ-DG 58-R/4. B, MN 4564-V/1. C, MN 4564-V/3. D, MN 4564-V/2. E, UFRJ-DG 58-R/3. F, UFRJ-DG 58-R/2. G, MN 4564-V/4. H, UFRJ-DG 58-R/5. I, antero-posterior sequence of the eight (A-H) chevrons.

R. tessonei, in contrast, each lamina becomes thicker and slightly wider, ending in a bulky bone, which may be an autapomorphy of the Patagonian species (Calvo and Salgado, 1995). Also, the chevrons of *R. tessonei* and *A. maranhensis* are very distinct. In the former, the chevron is an L-shaped structure with a posterior distal projection, while the latter is characterized by a haemal canal that is open dorsally with a relatively long shaft that is laterally compressed.

High caudal neural arches, as seen in *Amazonsaurus maranhensis*, are typical of the Diplodocoidea (Calvo and Salgado, 1995; Wilson and Sereno, 1998). The open haemal canals, in turn, suggest that it is basal diplodocoid (Calvo and Salgado, 1995; Upchurch, 1998; Wilson, 2002).

Basal diplodocoids were widespread in South America during the Aptian–Cenomanian (Bonaparte, 1996). In Africa, in contrast, current data suggest a

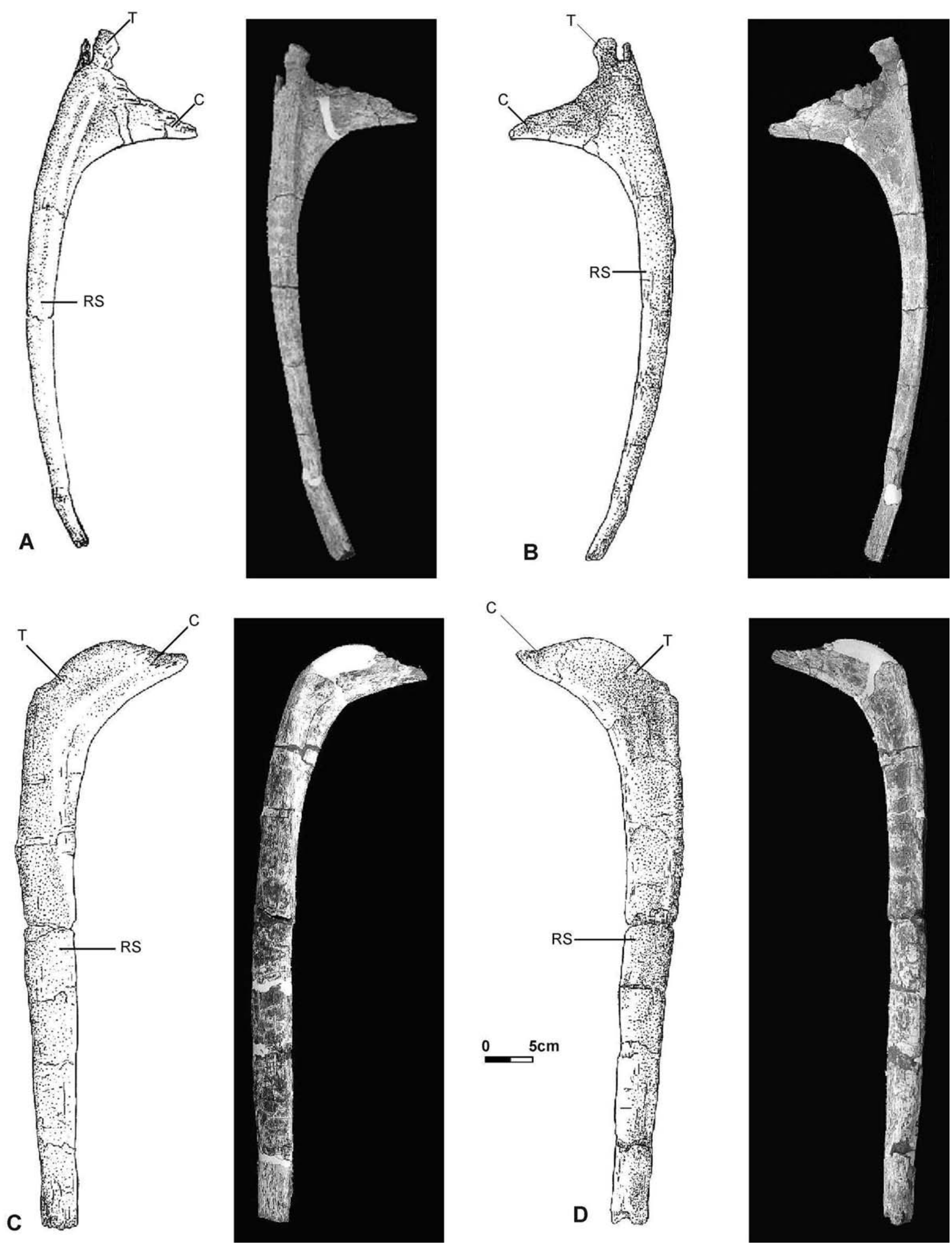

Fig. 15. Several thoracic ribs (MN 4562-V) in medial (A, C) and lateral (B, D) views.

distribution restricted to the northern part of this continent (McIntosh, 1992; Calvo and Salgado, 1995; Sereno et al., 1999; Medeiros, 2001; Apesteguía et al., 2001), with the possible exception of *Algoasaurus bauri,* a Lower Cretaceous sauropod from South Africa that may be a rebbachisaurid (Canudo and Salgado, in press).

The record of a rebbachisaurid in the Lower Cretaceous of Iberia (Pereda-Suberbiola et al., 2001) suggests that these dinosaurs might have had an even

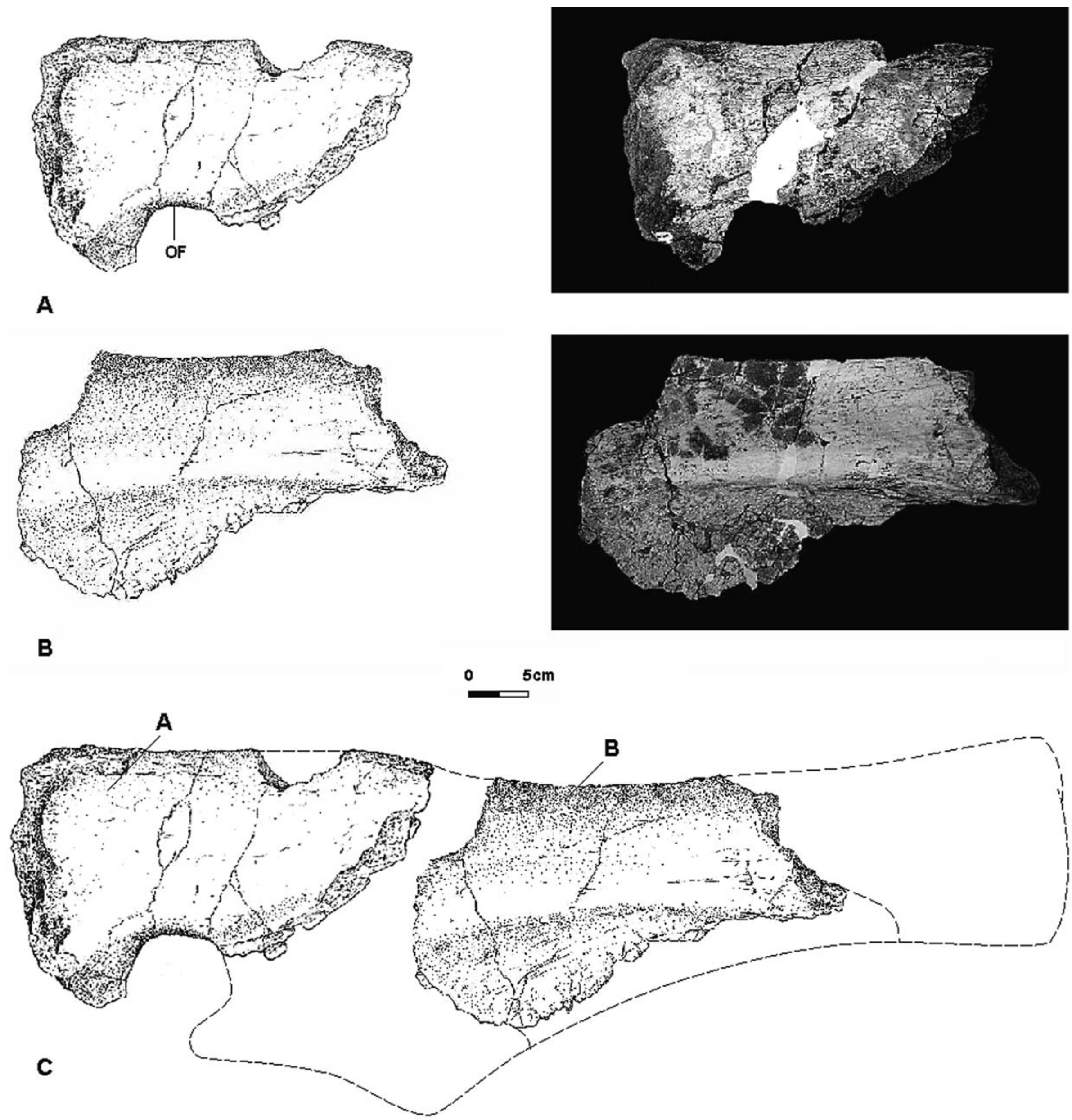

Fig. 16. Right pubis (MN s/n°-V). Isolated fragments (A, B) and the reconstruction of pubis (C).

wider geographical and temporal distribution. In fact, recent phylogenetic analyses suggest that the minimum age for the cladogenesis of the Rebbachisauridae is Mid–Upper Jurassic (Sereno et al., 1999), a period during which terrestrial dispersal between Gondwana and Laurasia was probably still feasible. In this regard, it is possible that the apparent absence of rebbachisaurids in the mid-Cretaceous of Laurasia is a result of regional extinction (Canudo and Salgado, in press).

The occurrence of a new basal diplodocoid in the Aptian–Albian of northern Brazil reinforces the idea of a South American-African community of dinosaurs represented by basal diplodocoids and titanosaurs among the sauropods, and carcharodontosaurids and spinosaurids among the theropods (Calvo, 1999; Vilas Boas et al., 1999; Medeiros, 2001; Medeiros and Schultz, 2001).

Intense tectonism, associated with the opening of the South Atlantic, occurred during this time throughout Gondwana. This led to the Serra Geral volcanism, the origin of new interior sedimentary areas (the Bauru, Caiuá and Sanfranciscana basins), and the uplifting of structural arches (Milani et al., 1994; Coimbra and Fernandes, 1995; Fulfaro and Perinotto, 1996; Potter,

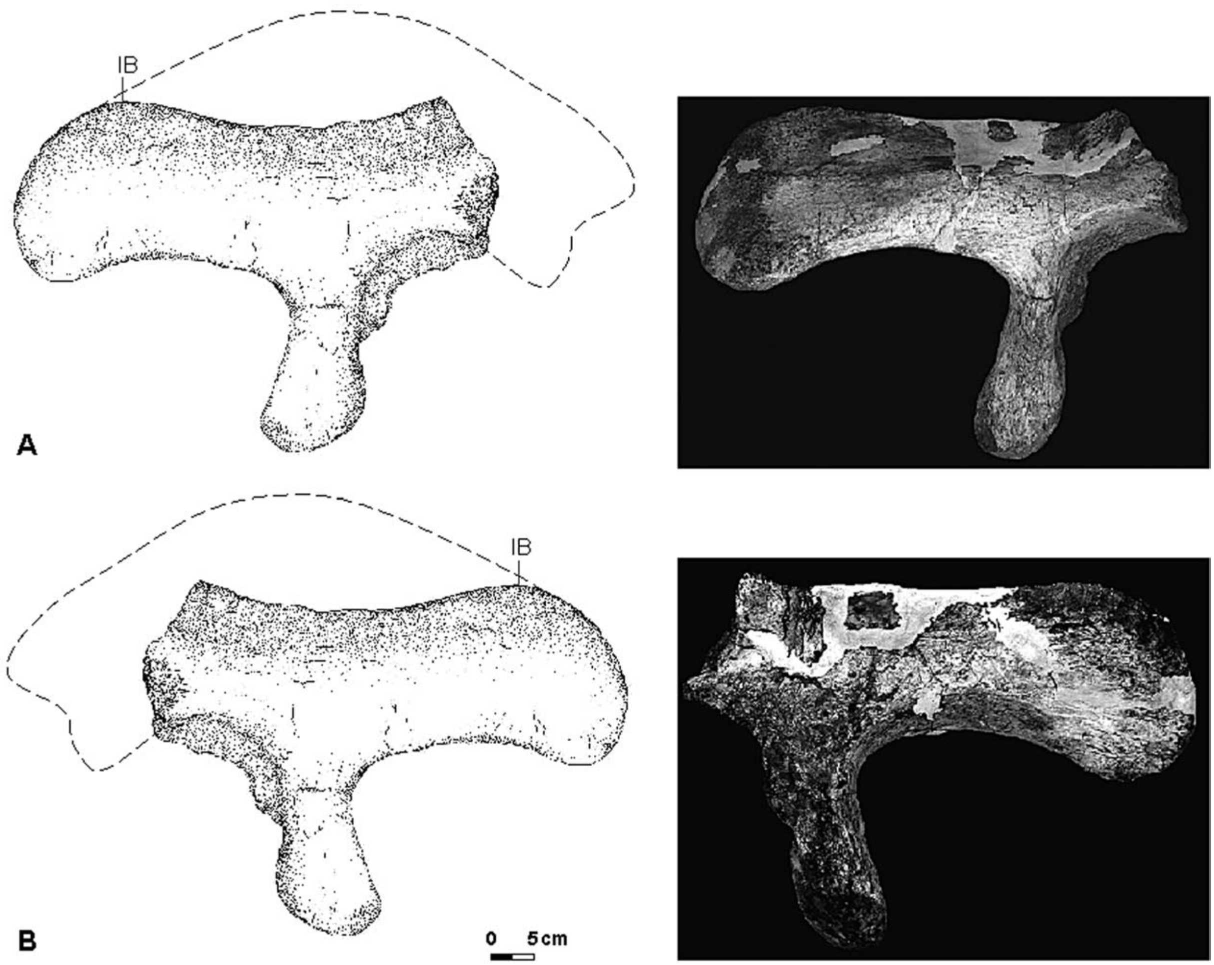

Fig. 17. Left ilium (UFRJ-DG 58-R/1) in lateral (A) and medial (B) views.

1997; Fulfaro et al., 1999; Paula e Silva et al., 1999; Musacchio, 2000). The structural arches and volcanic plateaus probably acted as barriers to the ranges of the existing ancestral species, isolating the biotas of north-northeastern Brazil from those of southern Argentina during the early (Neocomian) part of the Early Cretaceous.

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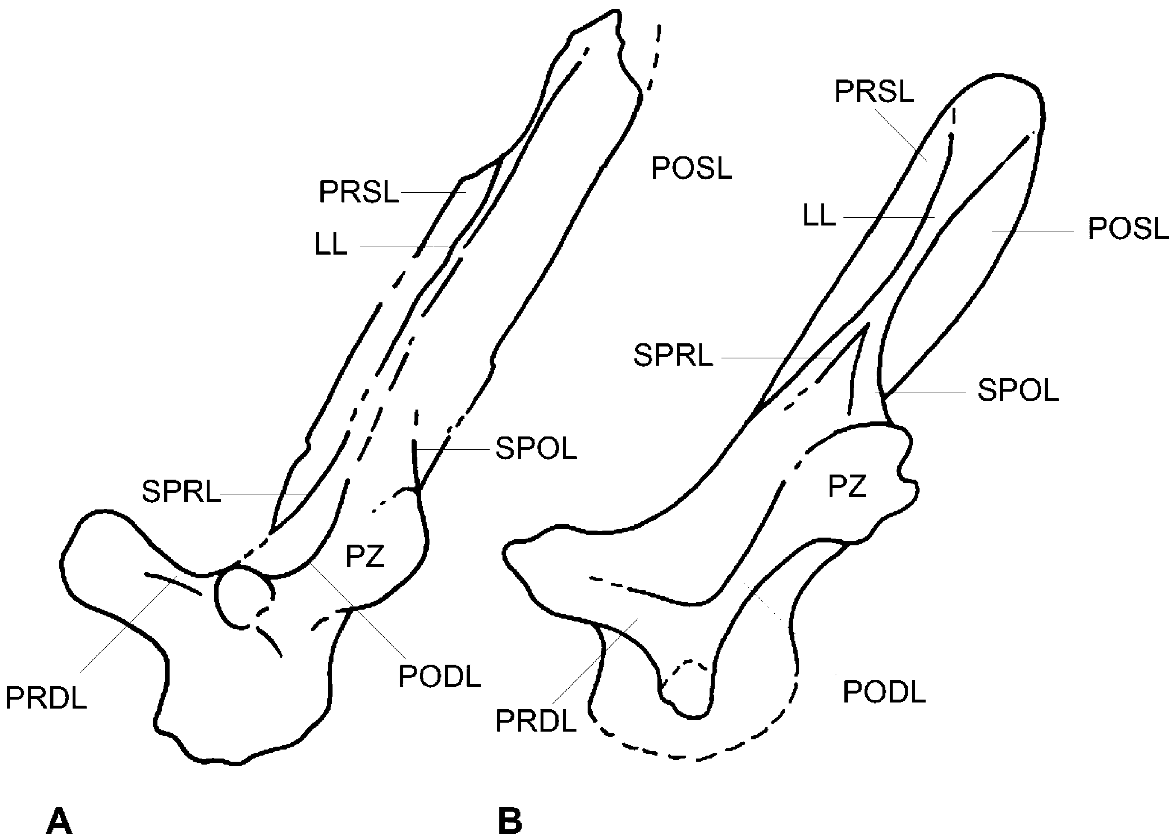

Fig. 18. Sketch showing the different diapophyseal laminae in the anterior caudals of *Amazonsaurus* (A) and *Barosaurus* AMNH 11657 (B).

Brazil), and Professor Reinaldo José Bertini and MSc. Rodrigo Santucci (Universidade Estadual Paulista-Rio Claro, Brazil).

Appendix A. Explanation of abbreviations noted on figures

AC, acetabulum; C, capitulum; CPOL, centropostzygapophyseal lamina; DP, diapophysis; F, foramen; HC, haemal canal; HS, haemal shaft; IB, iliac blade; ISP, ischial peduncle; ILP, iliac peduncle; LL, lateral lamina; NC, neural canal; NS, neural spine; OF, obturator foramen; P, parapophysis; PCDL, posterior centrodiapophyseal lamina; PL, pleurocoel; PODL, postzygodiapophyseal lamina; POSL, postspinal lamina; PZ, postzygapophysis; PP, pubic peduncle; PRZ, prezygapophysis; PRDL, prezygodiapophyseal lamina; PRSL, prespinal lamina; RS, rib shaft; SPDL, spinodiapophyseal lamina; SPOL, spinopostzygapophyseal lamina; SPRL, spinoprezygapophyseal lamina; T, tuberculum; AMNH, American Museum of Natural History; UFRJ-DG, Universidade Federal do Rio de Janeiro-Departamento de Geologia; MN-V, Universidade Federal do Rio de Janeiro-Museu Nacional, Coleção de Paleovertebrados.

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