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AN ARMOURED SAUROPOD FROM THE APTIAN OF NORTHERN PATAGONIA, ARGENTINA

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Abstract A new genus and species of Aptian sauropod, from the Lohan Cura Formation, is briefly described. It is based on an incomplete sequence of fragmentary dorsal, sacral, and caudal vertebrae, a tibia, a fibula, left metatarsals, and osteoderms, representing four morfo-types. The peculiar morphology of the osteoderms and of the top of the neural spines where the osteoderms were fixed, is considered sufficient characters to support setting up a new family of the Sauropoda the Agustinidae nov.

Introduction

During January and February of 1996 and 1997 the Museo Argentino de Ciencias Naturales of Buenos Aires, organized field seasons for paleontological explorations of the continental Aptian Lohan Cura Formation (Leanza and Hugo, 1996), exposed in Southern Neuquén Province, Northern Patagonia, a few kilometers west of the town of Picún Leufú.

The explorations were directed to discover terrestrial vertebrates of Aptian age in order to increase the information on the Cretaceous vertebrates of this region of South América. In 1996 significant remains of a new sauropod, at present under study, were discovered near the Arroyo China Muerta, some 50 km. west of Picún Leufú.

The material discussed in this paper is from an unusual sauropod discovered in 1997, which consists of well preserved dermal ossifications located above the neural spines, evidently capable of being moved by the animal. This armoured sauropod demonstrates the variety of unexpected adaptive types developed in South America as a result of the long isolation of the Gondwanan and Laurasian supercontinents during most of the Jurassic and Cretaceous (Bonaparte, 1986).

Systematic Paleontology

Sauropodomorpha Huene 1932
Sauropoda Marsh 1878

Agustiniidae fam. nov.

Characterization of the family.: Large sauropods provided with three or more types of dermal ossifications located along the vertebral column and above the neural spines: a) unpaired, transversely narrow dermal plates; b) unpaired, transversely broad dermal plates; and c) paired, elongated dermal plates.

Agustinia gen. nov.

Type species: *Agustinia ligabuei* sp. nov

Derivation of name: To honour the young student Agustín Martinelli, a member of the paleontological team and discoverer of the specimen.

Diagnosis: As in the species given below.

Agustinia ligabuei gen. et sp nov.

Derivation of name: To honour Dr. Giancarlo Ligabue, from Venezia, an active philanthropist, who supported the 1997 expedition to Patagonia.

Holotype: Specimen of the "Cármen Funes" Museum of Plaza Huincul, Neuquén Province, MCF-PVPH–110, represented by 3 incomplete dorsal, 6 incomplete sacral, and 10 incomplete caudal vertebrae; 9 dermal ossifications, almost complete right tibia and fibula; and 5 articulated left metatarsals.

Provenance: Upper section of the Lohan Cura Formation, Aptian; north side of Cerro El León, 8 km west from Picún Leufú, southern Neuquén Province, Argentina.

Diagnosis: Sauropod with the top of the neural spines transversely expanded in the last dorsal, all the sacral, and the three anterior caudal vertebrae. With three types of osteoderms articulating on the top of the neural spines: type a) unpaired leaf shaped, type b) laminar, transversely wide with lateral projections, and type c) elongate, flat or cylindrical, dorsolaterally projected. Fibula with a pronounced posterior projection on its proximal section, and a bend internally directed, bounding the cnemial crest of the tibia. Metatarsals of the type present in titanosaurs.

Description:

A sequence of 18 incomplete articulated vertebrae were collected in two blocks. One block contained 3 posterior dorsals, 6 sacrals and 2 anterior caudals; the second block held 8 anterior and median caudals. The position of the vertebrae indicate they were articulated, in natural position. Unfortunately, weathering destroyed a good portion of them, and only the central and dorsal sections of the neural spines were recovered, associated with a few complete dermal ossifications. The right tibia and fibula were articulated with the femur, which was represented only by hundreds of small weathered fragments, impossible to recover.

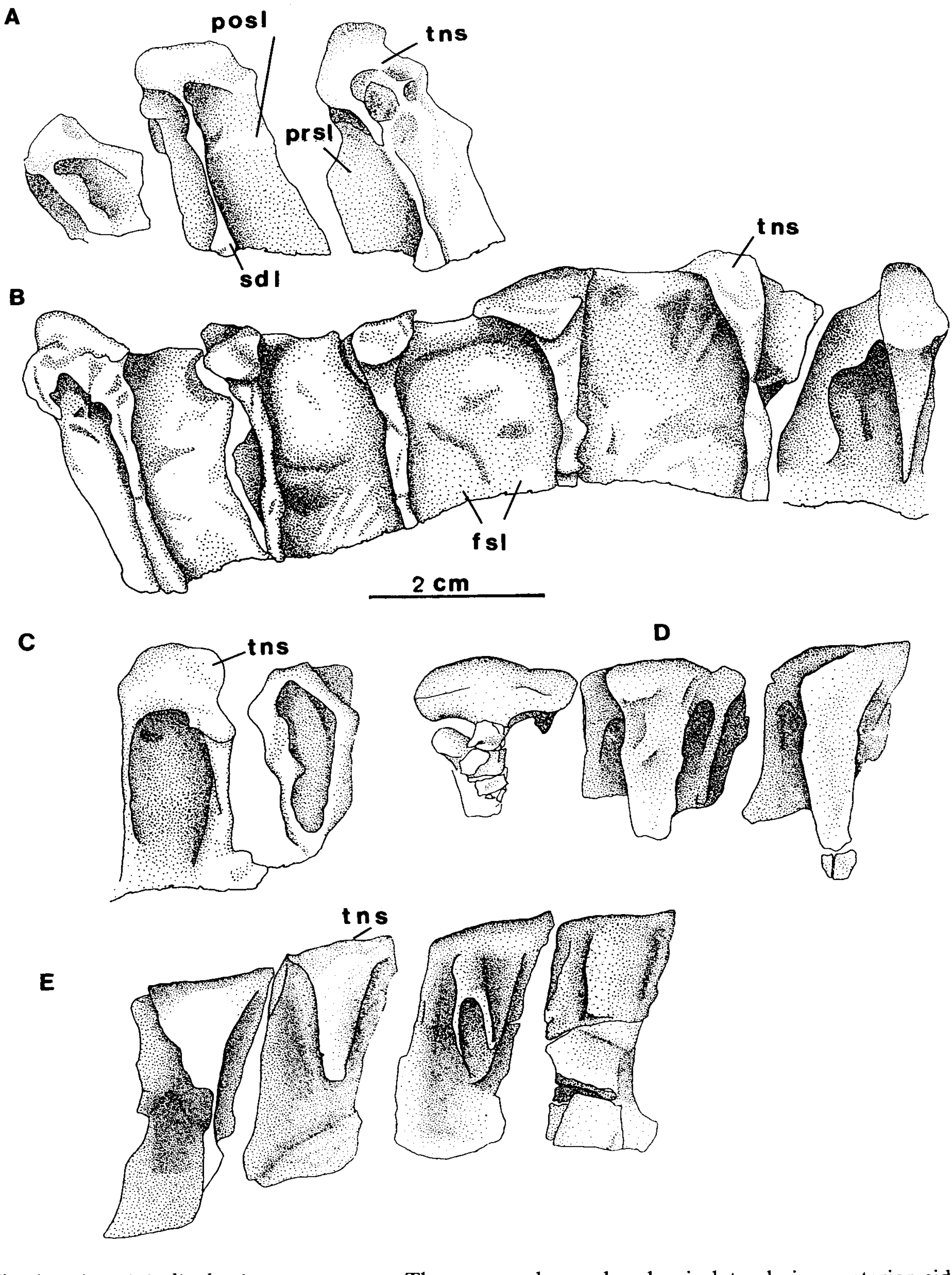

Fig. 1. *Agustinia ligabuei* gen. et sp. nov. The preserved neural arches in lateral view; anterior side to the left. A, the last three dorsal, incomplete neural arches; B, the six sacral, incomplete neural arches; C, the incomplete neural arches of caudal 1 and 2; D and E, sequence of seven incomplete neural arches of articulated caudal vertebrae. Abbrev.: FSL, fused spinal laminae; POSL, posterior spinal lamina; PRSL, prespinal lamina; SDL, supradiapophysial lamina; TNS, top of neural spine.

Dorsal vertebrae (Fig. 1A): There are 3 incomplete neural arches of the last dorsal vertebrae. The preserved parts include the top of the neural spines and their ventral continuation to a point higher than the zygapophyses. So, the information they provide is very limited. The top of each spine is transversely broad, rather rectangular, with a median posterior projection which merges into the postspinal lamina. The lateral side of the top of each spine continues down to the supradiapophysial lamina. This uppermost part of each spine is rather convex in anterior view, with flat dorsolateral surfaces, which appear to be the area of contact with the osteoderms.

The postspinal lamina is the more developed of the four laminae. The prespinal lamina is anteroposteriorly shorter, and the lateral laminae, which tentatively we interpret as supradiapophysial laminae, are even laterally shorter, although robust in their proximal portion.

Sacral vertebrae (Fig. 1B): The sacral vertebrae are also incomplete and represented only by the neural spines, fused with one another through the axial laminae. The union of the laminae makes a rather flat, broad surface, bordered by the pronounced ridges of the lateral laminae. The top of the neural spines is, basically, of the same morphology as those of the dorsals, with pronounced lateral expansions (Fig. 2), which continue down in the lateral laminae. This dorsally wide surface, as in the dorsals, suggests it was for accommodation of the osteoderms, possibly laterodorsally projected. There is no indication of sacral ribs, probably due to the fact that they were connected to the centra and to the lower section of the neural arches.

Anterior caudals (Fig. 1C): The three anterior caudals are also represented by the neural spines. The top of them are transversely expanded as in the sacrals and dorsals, but its width decreases in the posterior neural spines. In the anterior caudals the prespinal lamina is much larger than the postspinal lamina, this being only vestigial. The lateral laminae are well developed, prominent, in the caudal 1 and 2, but decrease rapidly backwards.

Central anterior caudals (Fig. 1D, E.): This section of the tail is very poorly represented. According to the position in the field of these incomplete but articulated vertebrae, they possibly represent the caudals 6 through 13. The width of the top of the neural spine

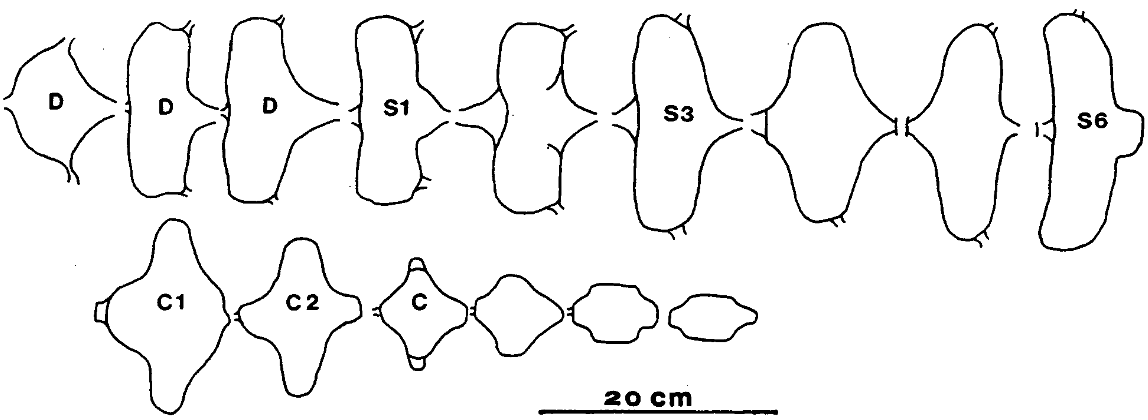

Fig. 2. *Agustinia ligabuei* gen. et sp. nov. Schematic figures of the reconstructed top of the neural spines. Abbrev.: C, top of neural spines of caudal vertebrae; D, of dorsal vertebrae; and S, of sacral vertebrae.

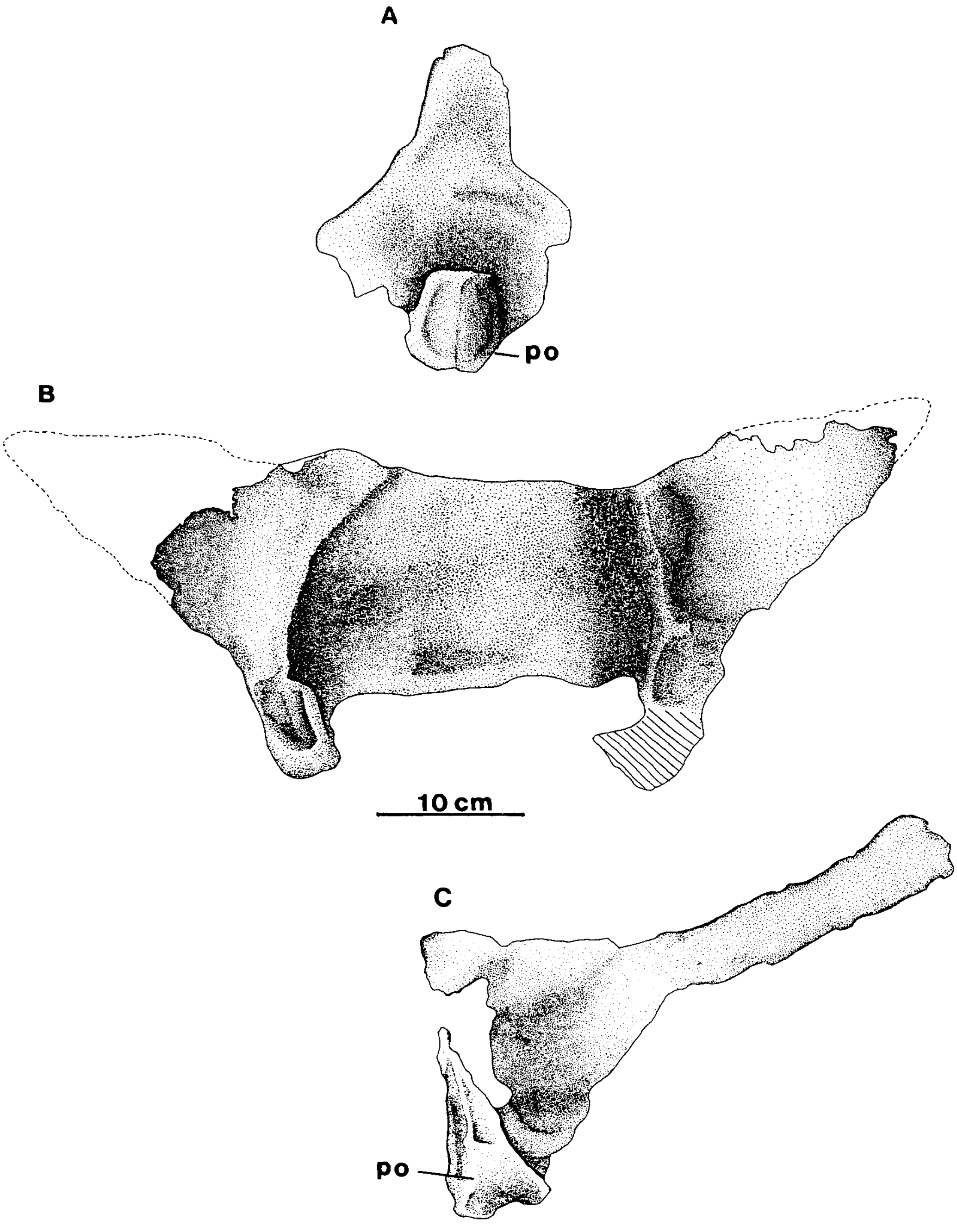

Fig. 3. *Agustinia ligabuei* gen et sp. nov. Osteoderms. A, Type 1; B, Type 2; C, Type 3. Abbrev.: po, thick proximal ossification.

decreases dramatically from 90 mm in the caudal 3 to 45 mm in the caudal 13. The reduction of the top of the spine is correlated with the relief of the lateral lamina, which are very well defined in caudals 6–8 changes to only a lateral rugosity in the spine of caudal 13.

Osteoderms (Figs. 3–5): There are eight rather complete, reasonably well preserved osteoderms. Six of them were in natural sequence, parallel to one another, and following the line of the posterior dorsal and sacral vertebrae. The remaining two osteoderms were isolated, evidently moved from their original position.

All of the oesteoderms consist of a large body, probably of a more external position, and one or two smaller, thicker pieces connected by soft tissues to the former and to the top of the vertebrae. Four types of osteoderms can be distinguished.

Type 1 (Fig. 3A). It is leaf-like in shape, dorsoventrally symmetrical, with the anterior? side convex and the posterior? concave. On the posterior and ventral surface it is attached to a dorsoventrally symmetrical, thick piece of bone, with a ridge on the plane of symmetry and a pair of lateral, concave surfaces. Possibly the thick piece of bone was connected by soft tissues to the top of the neural spine, on an anterior dorsal or cervical vertebra. Possibly this osteoderm had a median position, as it is an unpaired ossification. We have not conclusive evidence to prove that it had an anterior position along the vertebral column. But, its symmetry and the position where it was found do not contradict this assumption.

Measurements: Dorsoventral length of laminated ossification: 200 mm
Transverse width of same: 210 mm.
Dorsoventral length of thick ossification: 85 mm.
Maximum thickness of osteoderm: 40 mm.

Type 2 (Fig. 3B). It is rectangular, possessing a pair of projections laterodorsally directed. These projections are anteroposteriorly flattened and dorsoventrally conical, suggesting that they are the core of spikes. The whole ossification is laminar, except for the presence of two robust "feet" which probably were fixed to the transversely broad dorsal part of the neural spine of a dorsal? vertebra. Dorsally, each "foot" continues to a prominent ridge bordering a large median basin, exposed posteriorly?. We interpret that this osteoderm was unpaired and that the "feet" may represent the "thick bones" fused to the laminar portion. The position of this type of osteoderm on the vertebral column is difficult to ascertain. However, we think it lay posterior to the "type 1". They appear to have been located on the anterior half of the dorsal vertebrae.

Measurements: Maximum transversal length: 640 mm.
Transverse length between the ridges: 260 mm.
Distance between middle of each "foot": 240 mm.
Average thickness of laminar area: 5 mm.
Anteroposterior thickness of "feet": 45 mm.

Type 3 (Figs. 3C, 4A). This type of osteoderm appears to be the split version of the Type 2, in two pieces, eventually separated along the axial plane. There are four osteoderms with a large, dorsoventrally expanded, laminar proximal region bifurcated in two branches. A solid piece of bone is attached to one of the branches.

This type of osteoderm is relatively short in comparison with Type 4. The lateral projection is rather flat except on one of them (Fig. 4A) where the shaft is subcircular and conical. The piece of bone located in the proximal area is about 14 cm along its longest axis, possibly of proximo-distal position. One side of this ossification is rather flat, and the opposite side bears three to four ridges, one on each border, and one or two ridges running distally? from a prominence of bone located near one of the borders. Those borders surround depressed basins which probably accomodated musculature.

Measurements: Maximum preserved length: 460 mm.
Height of proximal area: 215 mm.

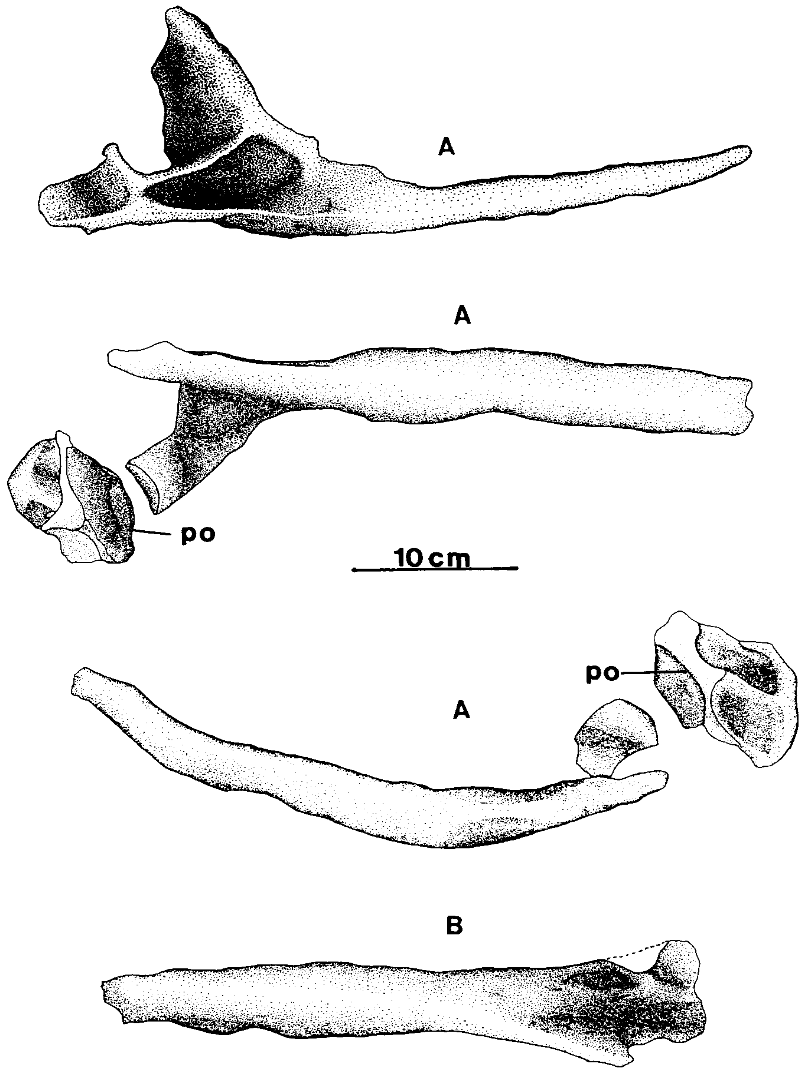

Fig. 4. *Agustinia ligabuei* gen. et sp. nov. Osteoderms. A, Type 3; B, Type 4. Abbrev.: as in figure 3.

Width of the stem: 50 mm.
Dorsoventral length of thick ossification: 130 mm.
Maximum transverse length of thick ossification: 70 mm

Type 4 (Figs. 4B, 5). This type is represented by three osteoderms, which are elongated, about 80 cm in length for the longest one, with the proximal region bifurcated, but less expanded than in Type 3. The proximal, thick piece of bone is not well preserved in these osteoderms. It seems to be smaller and with less relief than in Type 3.

Measurements: Maximum length: 760 mm.
Proximal dorsoventral length: 150 mm.
Width of the stem: 60 mm.

Tibia and Fibula (Fig. 6): The right tibia and fibula are preserved, not in the best condition because of lateromedial compression and the missing distal part of the tibia. Both bones are of similar length, 84 cm. The posterior border of the tibia forms a gentle concave line that terminates near the dorsal area, making a pronounced and thin posterior crest,

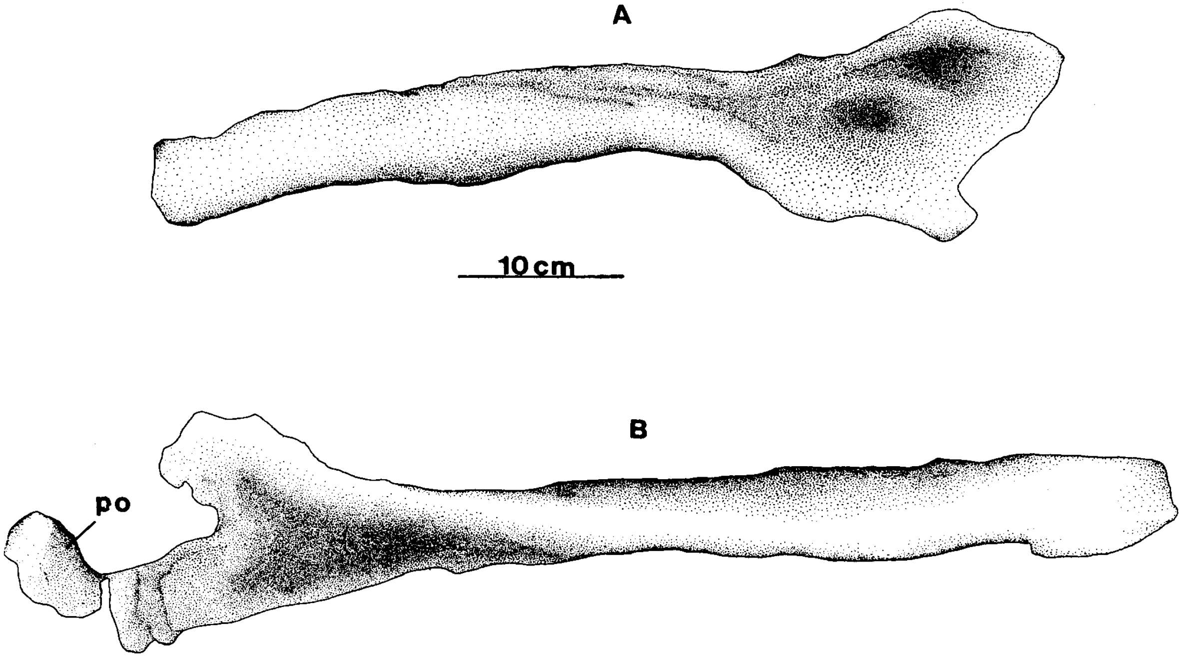

Fig. 5. *Agustinia ligabuei* gen. et sp. nov. Osteoderms. A-B, Type 4. Abbrev.: as in figure 3.

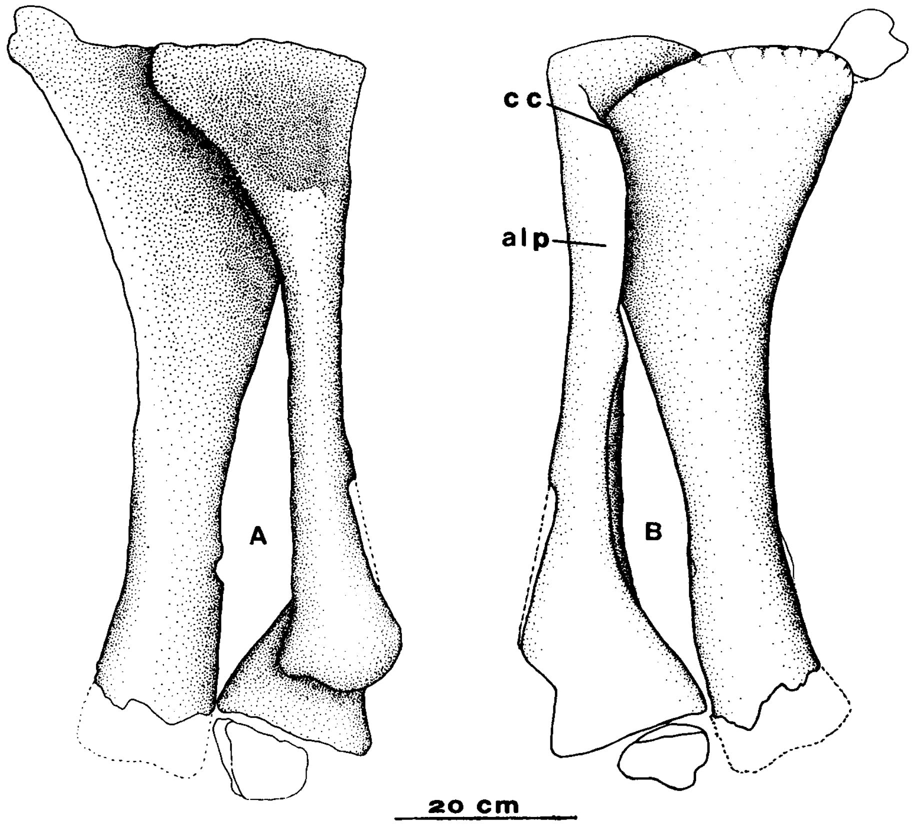

Fig. 6. *Agustinia ligabuei* gen. et sp. nov. A, lateral view of the right tibia and fibula as preserved. B, internal view of the same. Abbrev.: alp, anterolateral process of the fibula; cc, cnemial crest.

which projects backwards. All the dorsal half of the tibia is broad, but most of the distal half is anteroposteriorly narrowed. This suggests a more slender condition for the tibia of *Agustinia* than that of *Antarctosaurus*, (Huene, 1929) or *Saltasaurus* (Bonaparte and Powell, 1980; Powell, 1992). The anterior border is straight, with a poorly developed cnemial crest.

The fibula has a posteriorly greatly expanded lateral surface, similar to that of the tibia. Over most of its length, except in the distal area, the fibula is transversely thick, even more so than the tibia. As preserved, the fibula shows a dorsoventral groove on its internal and anterior surfaces to accommodate the anterior section of the cnemial crest.

Distally, the fibula is expanded anteroposteriorly, forming a large articular area for tarsal bones. The internal side of the fibula is flat, wide and passes into the anterior side, giving a twisted appearance to the bone. The anterolateral trochanter is located in the proximal one quarter of the fibula.

Measurements: Preserved length of the tibia: 840 mm.
Maximum proximal width of the tibia: 340 mm.
Minimal width of the tibia: 105 mm.
Length of the fibula: 895 mm.
Maximum width in the proximal area: 250 mm.
Maximum width of distal end of fibula: 220 mm.

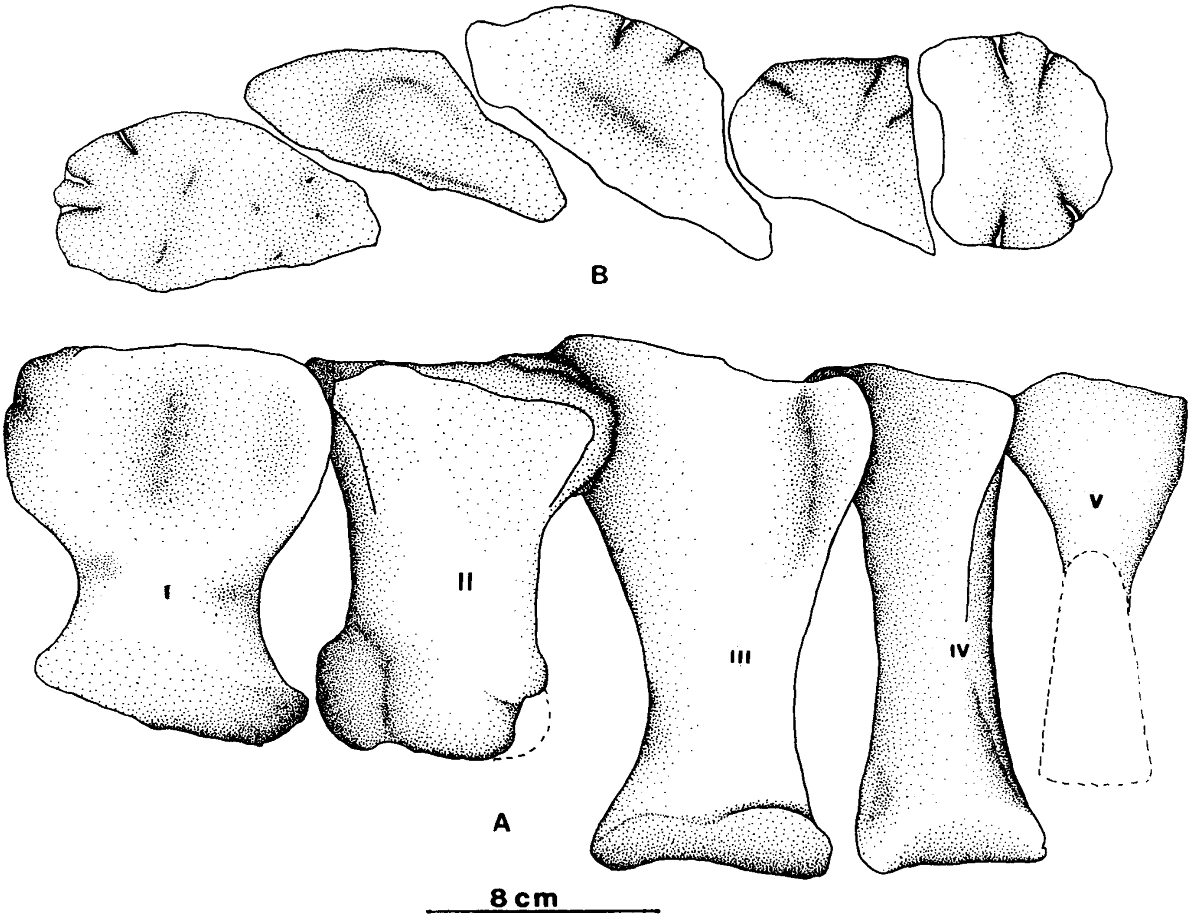

Fig. 7. *Agustinia ligabuei* gen. et sp. nov. Left metatarsals. A, in anterior view as preserved.; B, proximal view, with some correction of the position of them.

Minimum width of fibula: 80 mm.
Thickness of shaft of fibula: 80 mm.

Metatarsals (Fig. 7): The five metatarsals of the left foot are preserved, except for the distal half of metatarsal V. As in the case of the tibia and fibula, the metatarsals are deformed, raising doubts to the anatomical interpretations of them. Fig. 7A shows them in anterior view, illustrated as they were found. Because of dorsoventral deformation the proximal contact between them is altered, which has been partially corrected in Fig. 7B.

Metatarsal I is short, with the proximal end broader than the distal, the latter lacking condyles for the phalanx. The lateromedial constriction lies well below the middle of the bone.

Metatarsal II is about the same length as metatarsal I but more slender, with both distal and proximal expansions smaller. The condyles for the phalanx are well defined, with a pronounced groove between them. There is no apparent torsion between the proximal and distal areas, probably due to deformation.

Metatarsal III is longer than metatarsals I and II, with a proportionally smaller proximal expansion. The distal articulation is, in part, anteriorly projected, with a shallow groove separating both condyles for the phalanx.

Metatarsal IV is slender, with a narrower shaft and smaller proximal expansion than in metatarsal III. Both proximal and distal ends are subcircular, the distal one anteriorly projected.

Metatarsal V is represented by only the proximal half. What is preserved does not give indications of a reduced condition. The proximal end is even larger than that of metatarsal IV, and not of different robustness than the rest of the metatarsals. According to what is preserved, and as it is normal with metatarsal V in Cretaceous sauropods, its length was probably a bit less than metatarsal IV.

Measurements (in mm):

	Length	Transversal width of the proximal end
Metatarsal I	155	125
Metatarsal II	155	122
Metatarsal III	210	140
Metatarsal IV	205	85
Metatarsal V	–	80

Comparisons

The material of *Agustinia ligabuei* gen. et sp. nov., is not ideal for useful comparisons, because of the fragmentary nature of vertebrae preserved, the strongly compressed tibia and fibula, and the deformed metatarsals. However, the general similarities of the metatarsals with those of sauropods strongly suggest it is a member of that group of dinosaurs, and not a theropod or an ornithischian. In the latter group metatarsal I and V appear to be more reduced, with more defined symmetry of the 5 metatarsals. However, *Stegosaurus* (Marsh, 1896, Plate. 47A) appears to have a similar metatarsal I.

Going into some details, the comparison of the metatarsals with those of *Antarctosaurus* *wichmannianus* (Huene, 1929, Lam.34), deposited in the Museo Argentino de Ciencias Naturales, Buenos Aires, and with the foot of *Diplodocus* and "*Morosaurus*" figured by Marsh (1896, Plate 5429, 1–2), show enough similarities in basic morphology and in many details as to assume that the metatarsals correspond to a sauropod.

The tibia and fibula do not contradict the identification that *Agustinia* is a sauropod, in particular because the fibula is not reduced, showing a very large proximal section, expanded posteriorly and medially. In the Stegosauria and Ankylosauria the fibula is slender, showing a great disparity of size with the tibia. In the titanosaurian sauropods, such as *Antarctosaurus* (Huene, 1929), *Saltasaurus* and *Neuquensaurus* (Powell, 1986; 1992), the fibula is proportionally better developed, larger than in Stegosauria and Ankylosauria.

Finally, the morphology of the preserved parts of the neural arches, both dorsals and sacrals, show they are made of four laminae: the prespinal and postspinal làminae on the axial plane, and the inferred supradiapophysial laminae transverse to the former. In *Stegosaurus* the construction of the neural spine is not made up of laminae, but it is only a simple tubular plate with a dorsal swelling, as is also the case in *Kentrosaurus* (Janensch, 1927; Galton, 1982), and *Dacentrurus* (Galton, 1991)

Summing up, the morphology of the metatarsals, tibia and fibula, and vertebrae, strongly suggest that *Agustinia ligabuei* is a member of the Sauropoda. I understand that in the present state of knowledge of this armoured dinosaur it is difficult to make comparisons with the families of Sauropoda to obtain some information on its relationships. However, and within a limited range of comparisons, it is possible to admit that, based on the morphology of the neural spine, with four laminae at right angles, *Agustinia* is more similar to members of the Rebbachisauridae (*Rebbachisaurus garasbae* and "*Rebbachisaurus*" *tessonei*) than to those of the Titanosauridae Powell (1986; 1992). In the latter, the projection of the laminae is different, and the prespinal lamina is larger than the postspinal lamina, while in *Agustinia* it is the reverse.

Possibly the presence of such heterogeneous types of osteoderms and the notably expanded top of the neural spines may be enough characters to propose a new family of Sauropoda, the **Agustinidae** nov.

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