A new ornithopod (Dinosauria; Ornithischia) from Antarctica

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ABSTRACT

A new ornithopod dinosaur from Antarctica, *Trinisaura santamartaensis* n. gen. et n. sp. is diagnosed by a unique combination of characters that includes a scapula with a spike-like acromial process with a strong and sharp lateral crest and longer than other ornithopods, a humerus with a rudimentary deltopectoral crest represented as a thickening on the anterolateral margin of the humerus, and shaft strongly bowed laterally, and an ischium gently curved along its entire length. The holotype specimen comprises vertebral and appendicular elements. The presence of axially elongate distal caudal vertebrae, pubis with long prepubic and postpubic processes, as well as a femur with a distinct anterior trochanter, pendant 4th trochanter and shallow anterior intercondylar groove constitute a combination of characters present in the Late Cretaceous Patagonian *Gasparinisaura*, *Anabisetia* and *Talenkahuen*. The materials were found on the surface enclosed in a hard sandstone concretion collected near the Santa Marta Cove, James Ross Island, from the lower levels of the Snow Hill Island Formation (Campanian). This is the first ornithopod taxon identified from this unit, and the second ornithischian dinosaur, after the ankylosaur *Antarctopelta oliveroi*. However, other ornithopod reports from nearby localities of James Ross and Vega islands in outcrops of the overlying Lopez de Bertodano Formation suggest that this clade was widely represented in the Campanian and Maastrichtian of the James Ross Basin, Antarctic continent.

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1. Introduction

The diversity of Antarctic dinosaurs currently known includes remains of both saurischians and ornithischians. Most of this record is represented by indeterminate remains that are only able to be diagnosed at high taxonomic levels like theropods (Molnar et al., 1996; Case et al., 2007), sauropods (Hammer and Hickerson, 1994; Cerda et al., 2012) and ornithopods (Hooker et al., 1991; Case et al., 2000; Novas et al., 2002; Coria et al., 2007). However, the knowledge about the dinosaur diversity recorded in Antarctica at an alpha taxonomy level is currently limited to only three species. Two of them, the theropod *Cryolophosaurus elliotti* Hammer and Hickerson, and the prosauropod *Glacialisaurus hammeri* Smith and Pol, come from the Hanson Formation (Early Jurassic; Elliot, 1996),

and the third is the ankylosaur *Antarctopelta oliveroi* Salgado and Gasparini, from the Snow Hill Formation (Late Cretaceous; Olivero, 2012). Such a limited record could be biased by the logistics involved in Antarctic explorations, which determinates significant investments and reduce timeframes to carry out field works. Thus, new advances on the recognition of a new Antarctic species produce a noteworthy improvement in our knowledge on the evolutionary history of extinct faunas from this southern continent.

During the 2008 Antarctic Summer Campaign supported by the Instituto Antártico Argentino, an incomplete and semiarticulated specimen of an ornithopod dinosaur was collected by two of the authors (JJM and RAC) from deposits of the Snow Hill Island Formation, in Santa Marta Cove, James Ross Island (Fig. 1A). The materials, preliminarily communicated by Coria et al. (2008), correspond to a sub-adult individual of a small ornithopod dinosaur that represents a new taxon, *Trinisaura santamartaensis* gen. et sp. nov. The remains of this new form were deposited in the same stratigraphical unit where the ankylosaur *Antarctopelta oliveroi* (Salgado and Gasparini, 2006) and an indeterminate lithostrotian sauropod (Cerda et al., 2012) were collected. In this contribution we describe this new taxon and analyze their phylogenetic relationships within the Ornithopoda.

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Institutional abbreviations: **MACN,** Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina; **MCF-PVPH,** Museo Carmen Funes, Paleontología de Vertebrados, Plaza Huincul, Neuquén, Argentina; **MLP,** Museo de La Plata, Argentina.

2. Geological setting

Late Cretaceous sedimentary rocks are only exposed around the northern part of the Antarctic Peninsula, on the South Shetland Islands and on the James Ross Island Group. The James Ross Basin includes an extremely thick sequence of Lower Cretaceous–Palaeogene marine sedimentary rocks, and is divided into three principal lithostratigraphic groups: the basal Gustav (Aptian–Coniacian), the intermediate Marambio (Santonian – Danian); and the upper Seymour Island (Palaeogene) groups (e.g., Rinaldi, 1982; Crame et al., 1991; Riding and Crame, 2002).

The finer-grained Marambio Group, about 3000 m-thick, is exposed on James Ross, Snow Hill, Seymour and the nearby Cockburn islands (Olivero et al., 1986, 1992; Pirrie et al., 1991, 1997; Olivero, 2012). The Marambio Group comprises shallow marine shelf deposits of the Hidden Lake, Santa Marta, Snow Hill Island and López de Bertodano formations (Fig. 1). The basal member of the Snow Hill Island Formation (formerly the upper Gamma member of

the Santa Marta Formation) is extensively exposed on the northeastern area of the Ulu Peninsula, at the Santa Marta Cove (Fig. 1). The lower two thirds of that member contains scarce invertebrate fossils (ammonites, gastropods and bivalves) preserved within inner shelf sandstones and coquinas (Olivero, 2012) (Fig. 1C), as well as dinosaur remains (Coria et al., 2007; Cerda et al., 2012), which include the new form here described.

3. Systematic palaeontology

Dinosauria Owen, 1842
Ornithischia Seeley, 1888
Ornithopoda Marsh, 1881
Trinisaura santamartaensis gen. et sp. nov.
Fig. 1C-5

Derivation of name: The generic name honors to Dr. Trinidad "Trini" Diaz, for her pioneer geologic studies on the Antarctic Peninsula. The specific name refers to Santa Marta Cove, where the holotype specimen was found.

Holotype: MLP08-III-1-1, disarticulated and partial skeleton that includes one incomplete dorsal vertebra, three sacral centra, seven
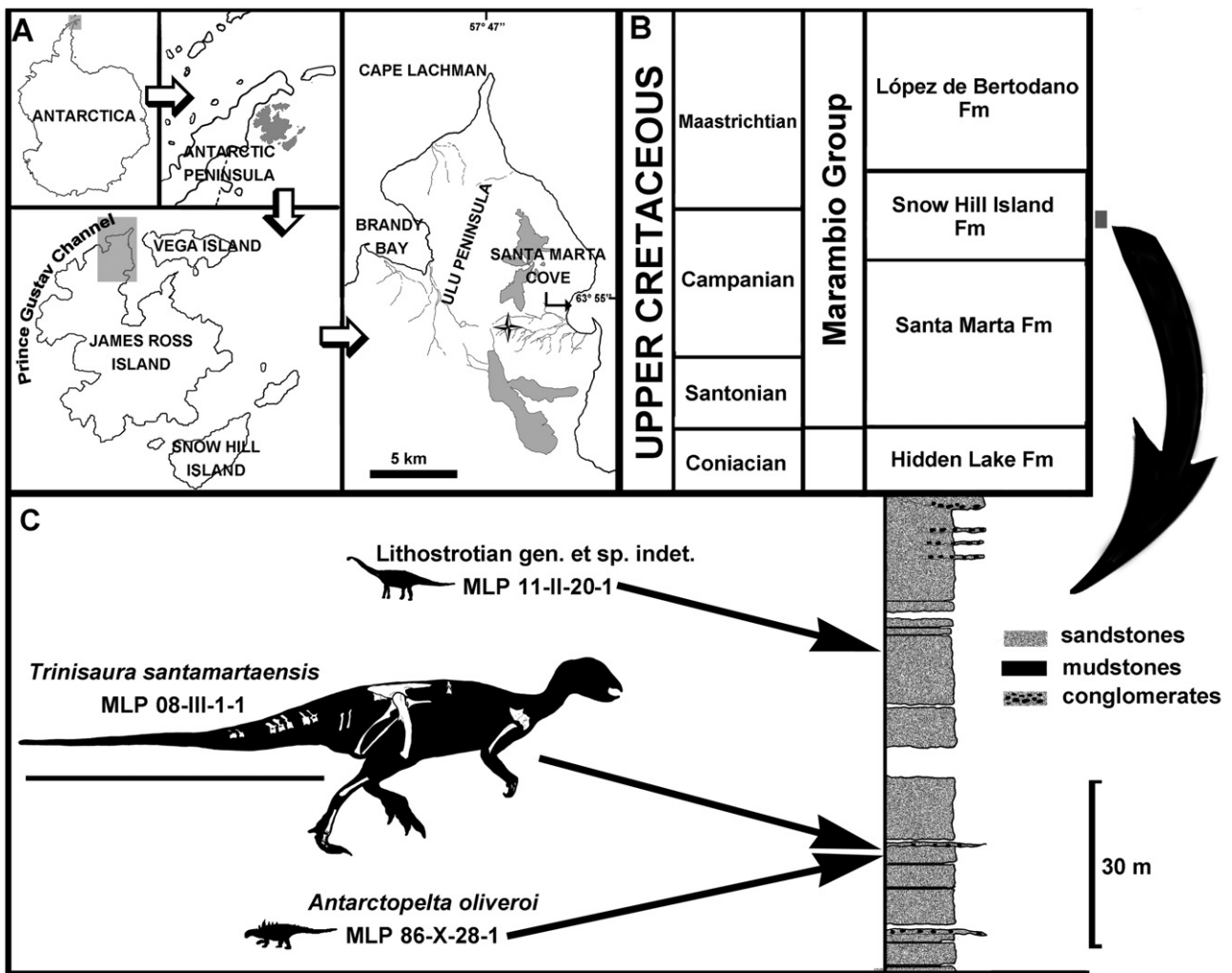
Fig. 1. A). Map showing the location where the holotype specimen of *Trinisaura santamartaensis* was collected. B) Stratigraphic chart with Upper Cretaceous formations in James Ross Basin (Antarctica). C) Outline reconstruction of the skeleton of *Trinisaura santamartaensis*, indicating preserved elements and stratigraphical position of the holotype specimen of *Trinisaura*, *Antarctopelta oliveroi* and a Lithostrotia indet. Scale bar: 1 m (only for *Trinisaura*). (A, based on Mussel, 1993, modified by Olivero EB [pers. comm., 2012]).

caudal vertebrae; two incomplete dorsal rib shafts, one proximal haemal arch, incomplete right scapulocoracoid, incomplete right humerus, two metacarpals, both ilia, right pubis, right ischium, right femur, right distal tibia, incomplete metatarsal III, first phalanx of pedal digit III, two phalanges of pedal digit IV, and indeterminate fragments.

Type locality: Santa Marta Cove, James Ross Island, Antarctica (Fig. 1A). The specimen was found on the surface, with many of the bones encased in hard sandstone concretions within a lithofacies comprised of thinly laminated fine to very fine sandstones (Fig. 1C).

Stratigraphic horizon: The stratigraphical provenance corresponds to the lower levels of the Snow Hill Island Fm. (upper Campanian, Upper Cretaceous) (Olivero, 2012) (Fig. 1B). GPS coordinates are kept at the Museo de La Plata and provided under request.

Diagnosis: *Trinisaura* is distinguished from other ornithopods by the presence of one autapomorphic character consisting in (1) a scapula with a spike-like acromial process with a strong and sharp lateral crest and longer than other ornithopods and the combination of the following characters: (2) rudimentary delto-pectoral crest represented as a thickening on the anterolateral margin of the humerus (convergent with *Talenkahuen santacru-censis* Novas, Cambiaso and Ambrosio, and *Anabisetia saldiviai* Coria and Calvo), (3) humeral shaft strongly bowed laterally (convergent with *Talenkahuen*, *Anabisetia* and some Marginocephalia Sereno), and (4) ischium gently curved along its entire length (convergent with some Marginocephalia) (diagnostic features 2–4 obtained after running cladistic analysis).

Description: The holotype specimen of *Trinisaura* represents, based on the femur length (Table 1), an individual of approximately 1.5 m long (Fig. 1C), which makes it similar in size to *Anabisetia* and adult specimens of *Gasparinisaura cincosaltensis* Coria and Salgado (Coria and Salgado, 1996; Salgado et al., 1997; Coria and Calvo, 2002). The single dorsal vertebra and all caudals show neural arches completely fused with their centra, although sacral centra are separate and isolated. However, considering that scapula and coracoids are solidly fused, we consider that the holotype specimen of *Trinisaura* could represent a sub-adult individual.

Vertebral column: The dorsal vertebra recovered belongs to the posterior section of the presacral series. It lacks the neural spine, the prezygapophyses, and most of the diapophyses and para-pophyses, although the base of a well developed prespinal lamina can be observed. The postzygapophyses are short and posteriorly projected. The lateral sides of the centrum are anteroposteriorly concave and small foramina are located anterodorsally, near the suture between centrum and neural arch. The centrum is ventrally keeled.

The three sacral centra recovered are robust and slightly compressed transversely, with wide articular surfaces. Their lateral sides are shallowly excavated dorsally, right below the contact for the neural arch.

The caudal vertebrae have neural spines that are strongly projected posteriorly (Fig. 2). Based on its size, a probable anterior caudal neural arch possesses a well developed transverse process that is slightly expanded distally. The prezygapophyses are short and anterodorsally projected. The neural spine, although missing the distal end, is strongly posteriorly projected and bears a well developed prespinal lamina, which forks anteriorly to connect with the prezygapophyses. The postzygapophyses are short, located underneath the neural spine, apparently at a level that surpasses the distal articular surface of the centrum. Mid-caudal vertebrae, which bear well developed transverse processes not distally expanded, are morphologically similar to those from other ornithopods. More distal caudals have small transverse processes, which disappear in the distalmost vertebral elements of the tail. These latter have lower neural arches, and centra that are propor-tionally longer anteroposteriorly.

Only one haemal arch was recovered. Based on its length, it is likely from the anterior third of the tail. It is transversely compressed distally, with the haemal canal dorsally closed. The distal end is slightly anteroposteriorly expanded although not as much as in *Gasparinisaura* (Coria and Salgado, 1996).

Scapular girdle: The proximal region of the right scapulocora-coid is preserved. Both scapula and coracoids are solidly fused to each other. The preserved proximal end of the scapula expands dorsoventrally (Fig. 3). The anteriorly projecting acromial process is spike-like and well developed. The anterior border is sharp, and the dorsal border is transversely thin and flat. Very little of the scapular blade is preserved. It is dorsoventrally narrower than the articular contact with the coracoids. The scapula participates in two thirds of the glenoid surface that is oriented ventrolaterally.

The coracoid is dorsoventrally as high as the proximal end of the scapula. The hook-like, distally blunt coracoid process is well developed, projects ventrally and medially in dorsal view. On the smooth and convex lateral side, the oval coracoid foramen is placed dorsally with an anterodorsal–posteroventral main axis. The medial side is smooth and concave. The glenoid articulation occupies one third of the glenoid cavity, is flat and faces posteriorly.

The humerus, which lacks both proximal and distal ends, is slender, laterally bowed and hollow although it is currently not possible to link that to pneumatization. The proximal end is transversely and anteroposteriorly expanded, mainly at its medial corner. The deltopectoral crest is reduced to a shallow thickening

Table 1
Measurements of appendicular elements of *Trinisaura santamartaensis*, holotype, MLP08-III-1-1.

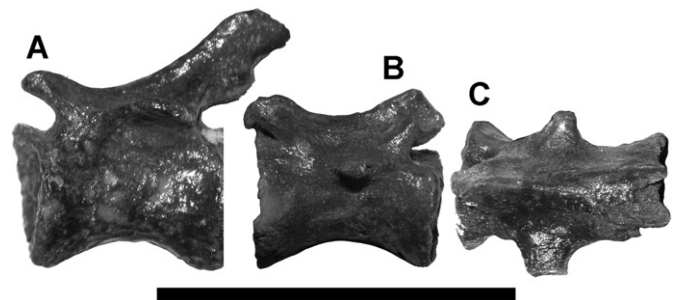|	Length	Shaft width	Shaft circumference	Distal width
Ilium	200	–	–	–
Prepubis	20*	11	40	–
Postpubis	210*	6	30	–
Ischium	215	11.5	40	26.5
Humerus	112*	8	45	–
Femur	220	22	80	49
Tibia	106*	24	75	34*
Metatarsal III	68*	18	6	24
Pedal phalanx III-1	45	15	60	22.5
Pedal phalanx IV-2	19	7	45	8
Pedal phalanx IV-3	8	10	40	7

Measurements in mm, * = as preserved

Fig. 2. Caudal vertebrae of *Trinisaura santamartaensis*. A) mid-caudal vertebrae in lateral view; B and C) distal caudal vertebra in lateral and dorsal views respectively. Scale bar: 5 cm.
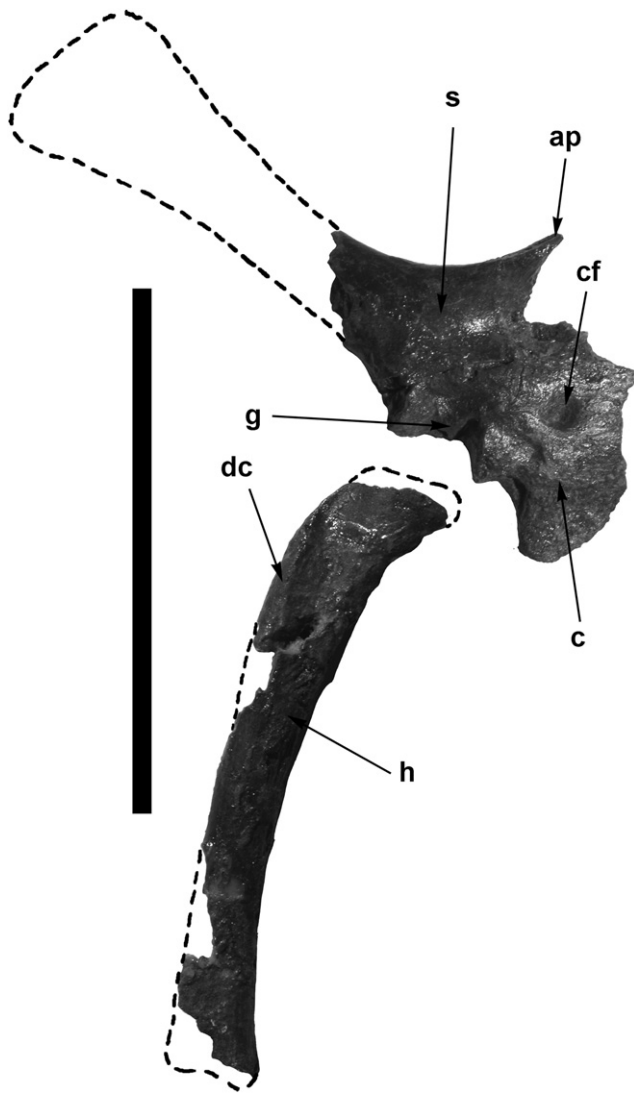
Fig. 3. Right scapulocoracoid and humerus of *Trinisaura santamartaensis* in lateral views. Abbreviations: ap, acromial process; c, coracoid; cf, coracoid foramen; dc, deltopectoral crest; h, humerus; g, glenoid; s scapula. Scale bar: 10 cm.

located on the lateral side of the proximal end as in *Anabisetia* (Coria and Calvo, 2002). The humeral shaft is transversely wider than anteroposteriorly. Distally, it expands transversely and possesses a shallow anterior groove, which likely separated both distal condyles.

Two metacarpals were collected and attributed to the holotype specimen of *Trinisaura* due to their association with the rest of the specimen. They are elongate bones, with triangular outlined proximal articular surfaces, shafts with transversely convex dorsal sides and flat ventral sides. One of the metacarpals is complete and preserves a convex articular proximal surface that is divided in two small condyles by a medial groove. The distal ends bear deep lateral pits for tendon attachments and convex articular surfaces also divided by shallow medial grooves.

Pelvic girdle: Both ilia are preserved. Whereas the right ilium lacks the distal end of the preacetabular process, the left ilium has not preserved most of the postacetabular process. Thus, the complete ilium anatomy is reconstructed by composing the features of both bones. The ilium of *Trinisaura* is a slender bone, low and elongate as in *Gasparinisaura*, *Anabisetia* and most basal ornithopods (Figs.4A; 6C,G). The dorsal edge describes a gently

sigmoid outline as most basal ornithopods like *Anabisetia* (MCF-PVPH-76), *Dryosaurus* (Galton, 1981) and *Gasparinisaura* (Coria and Salgado, 1996) (Fig. 6C–D). The preacetabular process occupies almost 50% of the total bone length. Proximally is as high as the pubic peduncle, and gently tapers anteroventrally. The lateral side is almost flat, but the medial one has a deep concave cross section, mostly due a well developed ventral lamina that projects medially, which probably contacted with the anterior sacral ribs. The post-acetabular process is robust, as high as the preacetabular process, although thicker transversely. It tapers posteriorly with a robust distal end. In lateral view, the ventral border is concave and hides the medial border of the brevis shelf, which is transversely wide as in *Anabisetia*. The distally tapering pubic peduncle projects ante-roventrally and has a sharp anterior border, rather concave lateral and medial sides, and a flat surface for the acetabulum. The ischial peduncle is not complete in either of the recovered ilia, although it seems to have been wide transversely and robust. In lateral view, the anterior and posterior borders of the acetabulum have an angulate outline.

The pubis is slender and, in spite of its missing distalmost tip, the preserved bone is longer than the ischium (Fig. 4B, Table 1). The incomplete prepubic process seems to be rod-like as in *Gaspar-inisaura* (Coria and Salgado, 1996) unlike the transversely compressed one of *Anabisetia* (MCF-PVPH-76) and more derived ornithopods (Fig. 6). The postpubic process is almost straight and rod-like, compressed transversely and dorsoventrally thick at mid-shaft. The process for the ischium is robust, but the oval obturator foramen is open.

The ischium curves ventrally in lateral view and medially in ventral view (Fig. 4C). The pubic process is squared in lateral view, and is transversely thin. The triangular obturator process is posi-tioned proximally, distal to which the mid-shaft region is thicker, and the ischiadic foot is transversely compressed. The inter-ischial symphysial area is restricted to the distal area of the shaft.

Hind limb: The almost complete right femur is robust with a straight shaft in anterior view and bowed anteriorly in lateral view. It lacks most of the femoral head and some areas of the bone's surface, which allows to observe a hollow inside (Fig. 5A–E). Both proximal and distal ends expand anteroposteriorly and trans-versely (Fig. 5A). In lateral view, the anterior trochanter is well developed, represents one third of the proximal lateral side, and it is separated from the greater trochanter by a narrow cleft as in *Anabisetia*. The fourth trochanter is well developed, placed on the proximal half of the shaft and projects posteriorly. Although broken, the fragile and thin morphology of the preserved base suggest it was pendant as in *Anabisetia*, *Dryosaurus*, *Gasparinisaura* and most basal ornithopods. The area corresponding to the basi-trochanteric fossa is not preserved due weathering. Unlike *Gas-parinisaura*, the femoral distal end has an anterior intercondylar groove (Fig. 5E) that is shallower than in *Anabisetia* and more derived ornithopods. The posterior intercondylar groove is well developed and wider than in *Anabisetia*, with the lateral (fibular) condyle extending more laterally, reminding the condition present in *Gasparinisaura*. The medial (tibial) condyle is wider that the fibular condyle.

Only the distal third of the right tibia is preserved (Fig. 5F). In anterior view, it is bowed laterally. The distal end expands trans-versely and its anterior side is slightly concave. In posterior view, there is a shallow medial and longitudinal groove. There is no evidence of fusion with the proximal tarsals, unlike as occurs in some specimens of *Anabisetia* (MCF-PVPH-75).

The metatarsus of *Trinisaura* (Fig. 5G) is only represented by the distal half of right metatarsal III. It has parallel lateral and medial sides, and the shaft is wider transversely than anteroposteriorly. The proximal area is broken and shows a triangular cross-section of
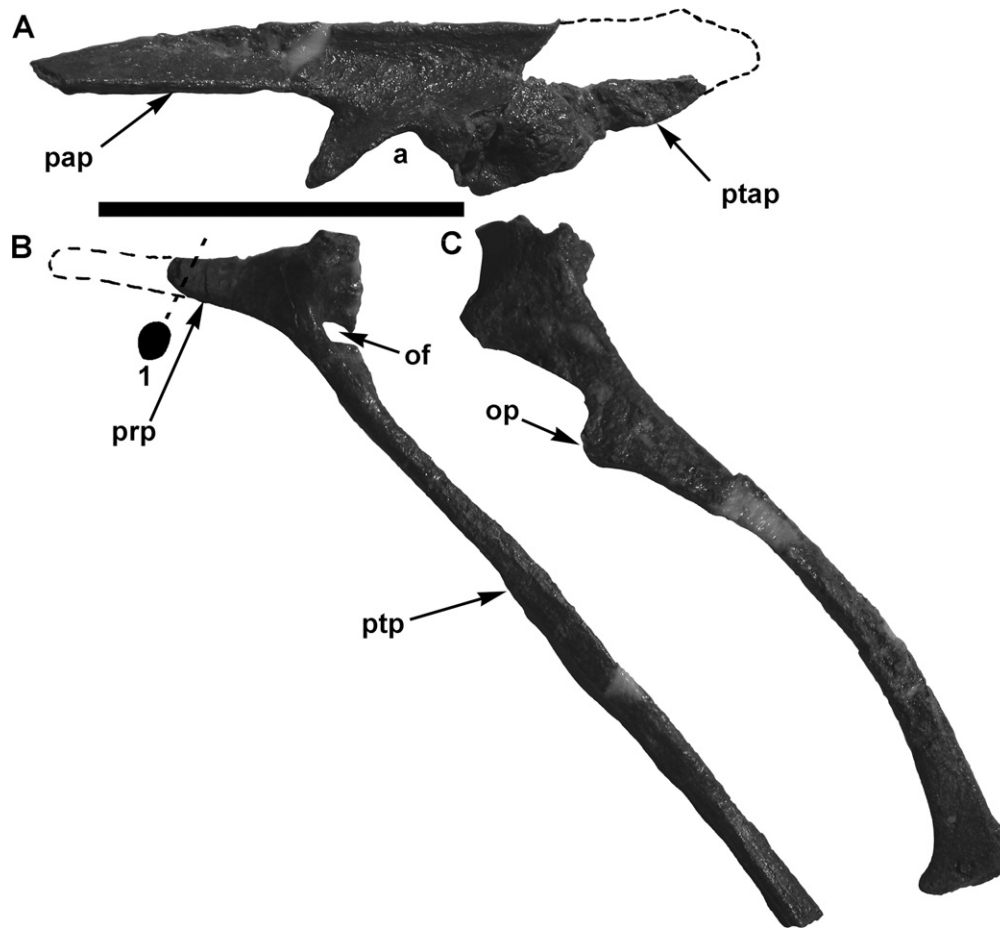
Fig. 4. Pelvic elements of *Trinisaura santamartaensis* in lateral views. A) ilium, B) pubis, C) ischium. Abbreviations: 1, cross-section of prepubic process; a, acetabulum; of, obturator foramen; op, obturator process; pap, preacetabular process; prp, prepubic process; ptp, postpubic process; ptap, postacetabular process. Scale bar: 10 cm.

the shaft. Both medial and lateral sides converge posteriorly, indicating the metatarsal III was wedged between metatarsals II and IV as in *Anabisetia* throughout most of its length.

The first phalanx of the digit III collected is robust as in most ornithopods. The proximal articular surface has a triangular outline, is expanded both anteroposterior and transversely and concave with a shallow medial edge. The distal end expands as does the proximal one and bears deep lateral pits for pedal tendons. Two phalanges attributed to the digit IV were also collected. They are rather stout, with ventral sides slightly wider than the dorsal, and probably represent phalanx II and III of digit IV.

4. Discussion

Autapomorphy discussion: As mentioned in the diagnosis, *Trinisaura santamartaensis* exhibits one unique feature, which is discussed below:

Scapula with a spike-like acromial process with a strong and sharp lateral crest and longer than other ornithopods. The presence of a spine-like acromial process in the scapula is observed in several ornithopods such as *Orodromeus*, *Othnielosaurus*, *Hypsilophodon*, *Thescelosaurus*, *Talenkahuen* and *Anabisetia*. In these forms, that spine-like acromial process is rather robust and dorsoventrally shorter than the minimal dorsoventral width of the scapular blade, which occurs posteriorly to the articulation with the coracoids. In contrast, the acromial process of *Trinisaura* is spike-shaped, very

slender, with a distinct sharp lateral edge and exhibits a greater dorsoventral development than in the aforementioned species, being as long as the width of the proximal area of the scapular blade (Fig. 3).

Phylogenetic discussion. The phylogenetic relationships of *Trinisaura* among the Ornithopoda were analyzed using the data matrix of Pol et al. (2011). The data matrix includes 52 taxa and 230 characters and was analyzed using equally weighted parsimony in TNT, version 1.1 (Goloboff et al., 2008). The results consisted of 72 MPTs with a length of 558 steps. After using the pruning tool of TNT, some taxa (*Echinodon*, *Lycorhinus* and *Yandusaurus*) were inactivated because of their instability (as in Pol et al., 2011), resulting in a single MPT with no change in the position of *Trinisaura*, nested within Cerapoda by the presence of a the ventrally oriented brevis fossa and the fact that the posterior portion of the brevis shelf cannot be seen in lateral view. Other Cerapoda synapomorphies of *Trinisaura* are the absence of a supra-acetabular 'crest' or 'flange', and a rod-like prepubic process. Further cerapod features include a distinct and elongate prepubic process, a femur with an anterior trochanter positioned proximally, which also approaches the level of the proximal surface of the femoral head, and is closely appressed to the 'dorsolateral'/greater trochanter (with no notch visible in medial view). *Trinisaura* shares with *Hypsilophodon*, *Gasparinisaura* and other Ornithopoda the presence of a tab-like obturator process on the ischium (Fig. 6). Also, *Trinisaura* appears as the sister taxa of *Anabisetia* and more derived Euiguanodontia, by the retention of an ischium with a mediolaterally compressed
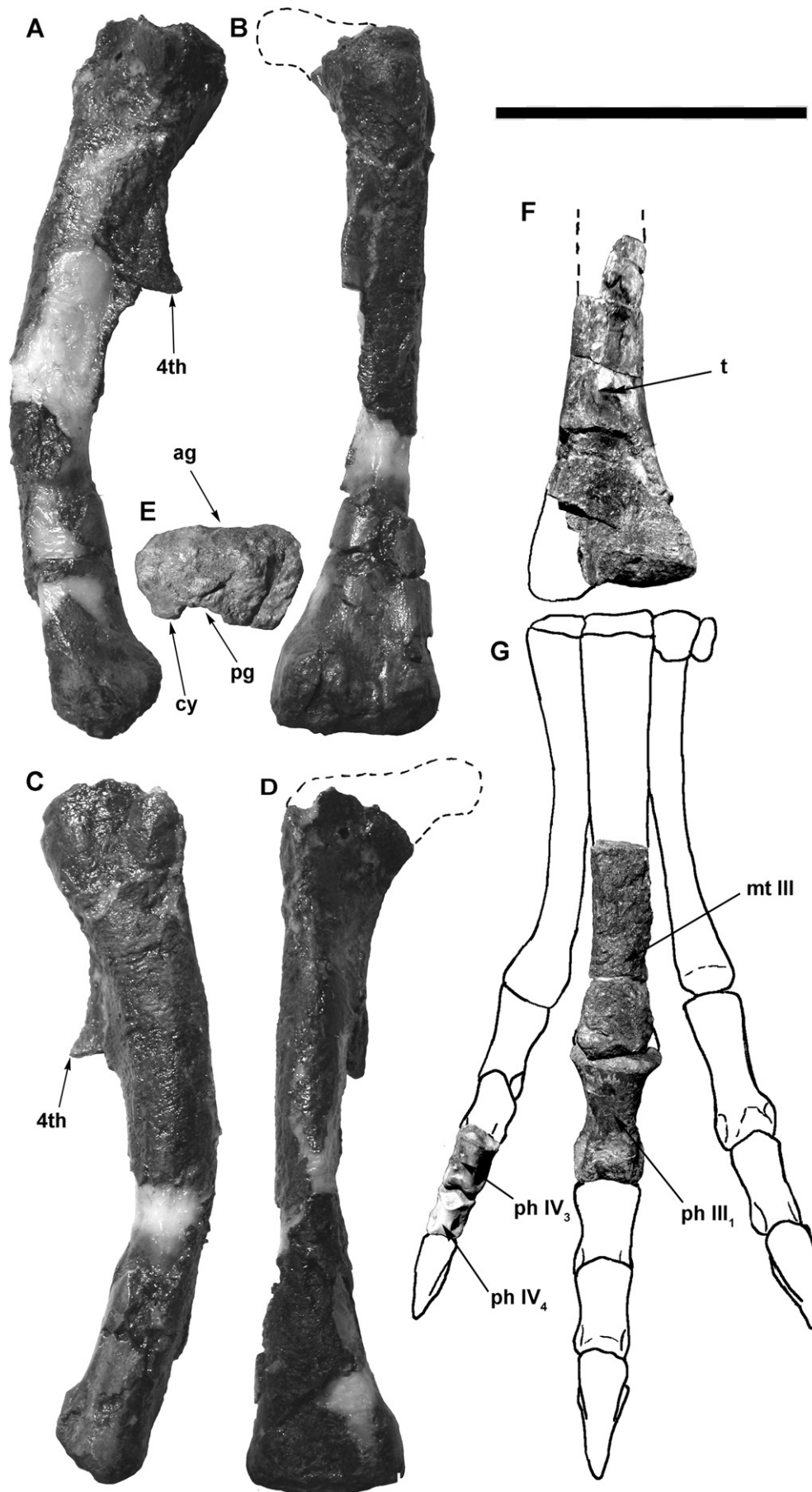
Fig. 5. Hind limb elements of *Trinisaura santamartaensis*. Left femur in A) lateral, B) posterior, C) medial, D) anterior and E) distal views; F) distal end of right tibia in anterior view; G) reconstruction of right pes in anterior view with distal end of right metatarsal III and pedal phalanges. Abbreviations: 4th, fourth trochanter; ag, anterior intercondylar groove; cy, condyle; pg, posterior intercondylar groove; t, tibia. Scale bar: 10 cm.
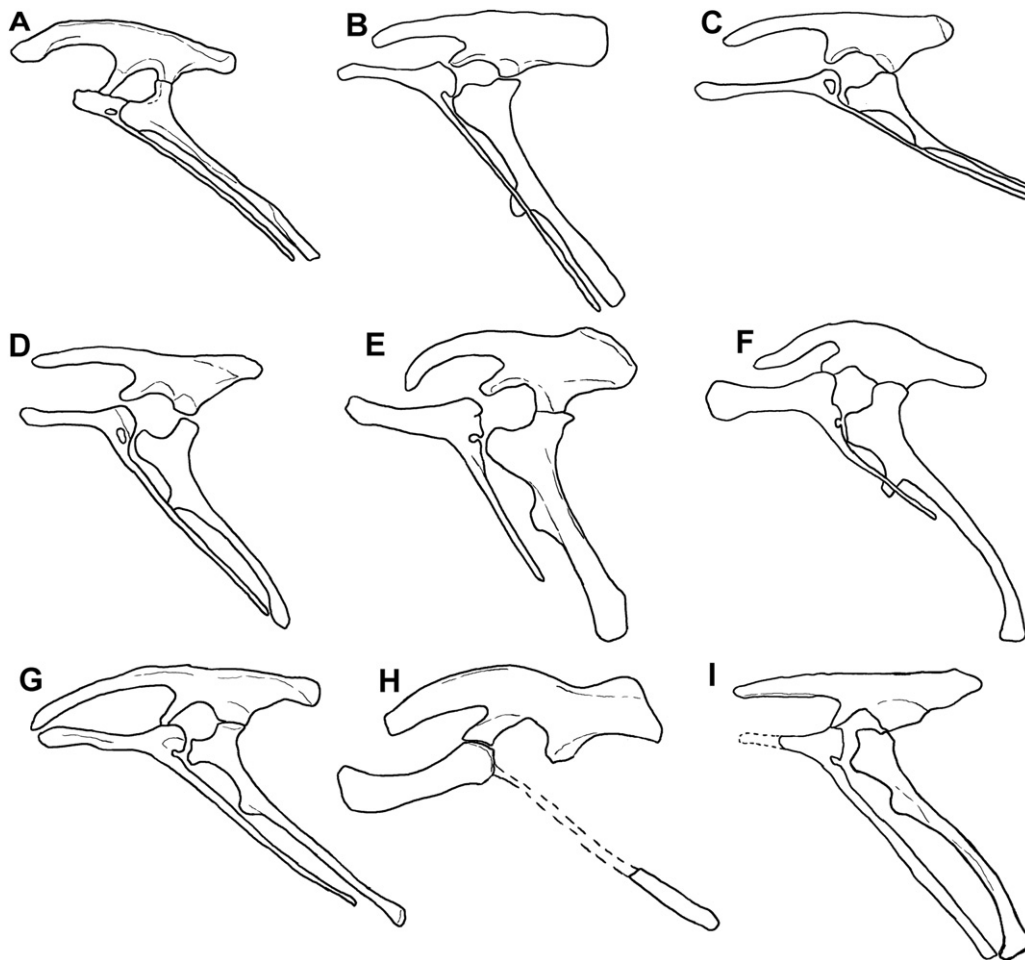
Fig. 6. Comparisons of the pelvic girdles in lateral view of (A) *Heterodontosaurus* (after Weishampel and Witmer, 1990), (B) *Hypsilophodon* (after Galton, 1974), (C) *Gasparinisaura* (Coria and Salgado, 1996), (D) *Dryosaurus* (after Galton, 1981), (E) *Tenontosaurus* (after Forster, 1990), (F) *Iguanodon* (after Norman, 1980), (G) *Anabisetia* (after Coria and Calvo, 2002), (H) *Talenkahuen* (after Novas et al., 2004), (I) *Trinisaura* (MLP-.08-III-1-1). Not to scale.

shaft that expands distally into a distinct 'foot', and a femur with a shallow anterior (extensor) intercondylar groove on the distal end, a laterally inflated medial condyle that partially covers the opening of the flexor groove, and the lateral condyle positioned relatively laterally and slightly narrower than the medial condyle (Fig. 7).

Antarctic ornithopod dinosaurs are currently recorded only in the Upper Cretaceous deposits of the James Ross Basin (Hooker et al., 1991, Milner and Hooker, 1992; Case et al., 2000; Novas et al., 2002; Coria et al., 2007). *Trinisaura santamartaensis* is the first dinosaur of that group from the upper Campanian Snow Hill Island Fm, and it was collected from the same locality as the ankylosaur *Antarctopelta oliveroi* (Salgado and Gasparini, 2006), indeterminate ornithopod fragments (Coria et al., 2007) and a fragmentary caudal vertebra of an indeterminate lithostrotian sauropod (Cerda et al., 2012). On the other hand, the Maastrichtian López de Bertodano Fm has yielded some fragmentary remains that include a basal Euornithopoda (Hooker et al., 1991) and one isolated hadrosaurid tooth (Case et al., 2000) from Vega Island, one incomplete ornithopod hind limb from James Ross Island (MACN-19777, Novas et al., 2002) and the distal end of a putative hadrosaurid metatarsal from Seymour (Marambio) Island (MLP-98-I-10-1). The basal Euornithopoda from Vega Island is represented by a 4–5 m long animal (*sensu* Hooker et al., 1991), which is at least twice the estimated size for the holotype specimen of *Trinisaura*. Nonetheless, due to a lack of further anatomical specifications, it is not possible to undertake comparisons with

Trinisaura. A similar limitation exists for a comparison with the specimen MACN-19777, which has been only mentioned in an abstract (Novas et al., 2004) and in an unpublished Doctoral Thesis (Cambiaso, 2007). Until a proper description of the specimens from the overlaying Maastrichtian López de Bertodano Fm is available,
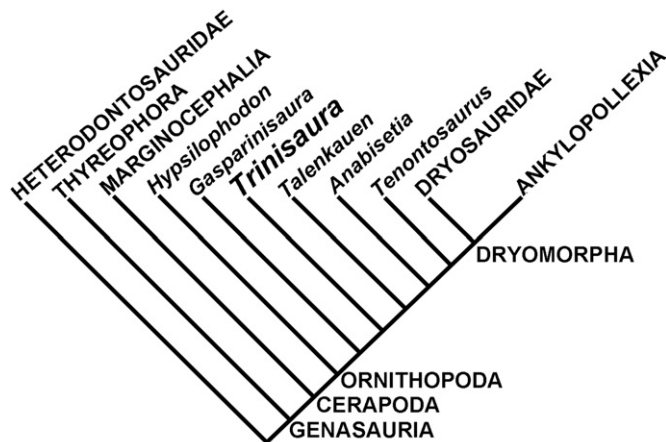
Fig. 7. Simplified cladogram of basal ornithopods depicting the phylogenetic position of *Trinisaura santamartaensis*.

their taxonomic distinction with *Trinisaura santamartaensis* is uncertain.

In this analysis *Trinisaura* results as more derived than *Thescelosaurus*, and is nested within a clade of ornithopods that includes all South American non-hadrosaurian ornithopods currently recorded (Fig. 6). Nonetheless, the present phylogenetic analysis does not show a South America − Antarctica ornithopod radiation. On the other hand, the available information about Australian and New Zealand ornithopods (Bartholomai and Molnar, 1981; Molnar and Galton, 1986; Rich and Rich, 1989; Wiffen and Molnar, 1989; Agnolin et al., 2010) is insufficient to elaborate an alternative relationship with *Trinisaura*. Further specimens and materials could provide a more complete set of data to improve the cladistic resolution of *Trinisaura*, and eventually, to propose a paleogeographical hypothesis for this new Antarctic form.

Acknowledgments

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Appendix 1

Character coding of *Trinisaura santamartaensis* based on the matrix published by Pol et al. (2011).

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