Journal of African Earth Sciences 122 (2016) 79–87

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

First evidence of *Hadrosauropodus* in Gondwana (Yacoraite Formation, Maastrichtian-Danian), northwestern Argentina

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ARTICLE INFO

Article history:
Received 28 March 2015
Received in revised form
20 January 2016
Accepted 15 February 2016
Available online 20 February 2016

Keywords:
Hadrosauropodus
Hadrosauridae
Yacoraite Formation
Late cretaceous
Gondwana

ABSTRACT

Uppermost Cretaceous (Campanian-Maastrichtian) large ornithopod tracks are scarce in Gondwana. This record is limited to few citations in the northern Argentina, Peru and possibly Bolivia, although their ichnological affinities are still under discussion. Recently, a new vertebrate tracksite with large ornithopod tracks has been found in the Maimará locality, Jujuy province, Argentina, from the Yacoraite Formation (Maastrichtian-Danian). The best preserved track is characterized by having large and bilobed heel impression and wide and short digit impressions with blunt claw marks. This record represents the unambiguous record of large ornithopod tracks in Gondwana in the Uppermost Cretaceous, and its features allow classifying it as *Hadrosauropodus*. Previously, this ichnotaxon had exclusively Laurasian distribution. Therefore, this record is the first evidence of *Hadrosauropodus* from Gondwana expanding the geographic range of this ichnogenus. A member of Hadrosauridae is reinforced as possible trackmaker of the *Hadrosauropodus* tracks. Uppermost Cretaceous hadrosaurid dinosaurs are scarce in Gondwana, being the record limited to Patagonia, La Pampa province and Antarctica. Therefore, the Maimará tracks increase the knowledge of this kind of dinosaur from Gondwana.

1. Introduction

Uppermost Cretaceous hadrosaurid dinosaur remains are not so abundant in South America (see Coria, 2014) as they are in Laurassian continents: North America (see Gates and Scheetz, 2014), Europe (see Dalla Vecchia, 2014) and Asia (see Bolotsky et al., 2014). Uppermost Cretaceous large ornithopod tracks, also called "hadrosaur tracks", are abundant in North America and Asia as well (e.g., Lockley et al., 2003; Xing et al., 2009; Díaz-Martínez et al., 2015, and references therein), but in Europe and Gondwana this record is very scarce (Lockley et al., 2003; Vila et al., 2013). To date, there are only four Campanian–Maastrichtian sites with large ornithopod tracks in Gondwana and all of them are located in South America: two in Argentina (Alonso, 1980; Alonso and Marquillas, 1986), one in Peru (Jaillard et al., 1993), and a possible record from Bolivia (Lockley et al., 2002).

Recently, a limestone slab with large ornithopod tracks has been found in the Maimará ichnosite, from the Yacoraite Formation (Maastrichtian–Danian, northern Argentina). The first vertebrate tracks from the Yacoraite Formation are known since the 70's of the last century (Alonso, 1978, 1980, 1989; Alonso and Marquillas, 1986). These authors have described the presence of theropod, sauropod, ornithopod, and avian tracks, and even some ichnotaxa have been formally named, such as *Hadrosaurichnus australis* Alonso, 1980, *Salfitischnus mentoor* Alonso and Marquillas, 1986, *Taponichnus donottoi* Alonso and Marquillas, 1986, *Telosichnus saltensis* Alonso and Marquillas, 1986, and *Yacoraitichnus avis* Alonso and Marquillas, 1986. Recently, new ichnological studies have been carried out in the Yacoriate Formation (e.g., Sánchez Rioja, 2004, 2005; Cónsole-Gonella and Aceñolaza, 2009, 2010; Cónsole-Gonella et al., 2010, 2012a, 2013; Cónsole-Gonella and Marquillas, 2014, and references therein).

The aims of this contribution are to describe in detail the new large ornithopod tracks found in the Yacoraite Formation, and discuss their ichnotaxonomy and some aspects about the preservation of this new dinosaur tracksite. Moreover, the tracks are compared with the general large ornithopod track record of the uppermost Cretaceous in South America, and we discuss their importance within the whole hadrosaurid record from Gondwana.

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http://dx.doi.org/10.1016/j.jafrearsci.2016.02.012
1464-343X/

2. Geological setting

2.1. Yacoraite Formation

The Yacoraite Formation represents a shallow epeiric unit that is the result of the marine transgressions in the Andean Basin of South America, caused by the high global sea level during the Late Cretaceus (Scotese, 1997; Hay et al., 1999; Marquillas et al., 2005, 2011, and references therein). The Yacoraite Formation is composed mainly of grey carbonates with varied depositional textures that are largely dolomitic, and in some of the proximal sections, conglomerates, calcareous sandstones and pelites. This formation is part of the Balbuena Subgroup (Late Cretaceous–Early Palaeocene), which is the early postrift deposit of the Salta Group (Early Cretaceous–Eocene), an intracontinental rift-type basin (e.g., Salfity and Marquillas, 1994; Viramonte et al., 1999; Marquillas et al., 2005; among others). The Salta Group is widely distributed in northwest Argentina and neighbouring regions (Fig. 1), and it is accumulated in seven subbasins: Tres Cruces, Lomas de Olmedo, Metán, Alemanía (Reyes, 1972; Salfity, 1982), El Rey (Salfity, 1980), Sey (Schwab, 1984) and Brealito (Sabino, 2002).

The palaeontological record of the Yacoraite Formation is abundant but lacking of diversity, according with the interpretation of the unit as part of an epeiric restricted sea (Marquillas et al., 2005, and references therein). This record is composed of ostracods, gastropods, bivalves, foraminifera and also fishes (Cónsole-Gonella et al., 2012b, and references therein). The ichnological record is composed of dinosaur and bird footprints (e.g., Alonso, 1980; Alonso and Marquillas, 1986; Cónsole Gonella et al., 2012a) and invertebrate trace fossils (Cónsole-Gonella et al., 2012b; Cónsole-Gonella and Marquillas, 2014, and references therein).

The formation has been dated as Maastrichtian–Danian on the basis of its dinosaur footprint record (Alonso and Marquillas, 1986), Maastrichnian and Danian palynomorphs (Moroni, 1982; Marquillas et al., 2007), and radiometric dating (Marquillas et al., 2011).

2.2. The Maimará section

The Maimará section is located at the Tres Cruces Subbasin (Fig. 2), the northern area of the Salta Group at 23°37′30.92″ S 65°23′56.07″ W.

The geology of the study area (Fig. 2) is composed of several units ranging from the Precambrian to the present, as a product of several tectonic events which have that configured a set of reversal faults that involved all units (Marquillas et al., 2005, and references therein).

In the Maimará section, only the lower and middle units of the Balbuena Subgroup -Lecho and Yacoraite formations-are exposed. This section is located nearly of the Salta-Jujuy high (Fig. 1), for this reason the strata arrangement of the Balbuena Subgroup is indicative of a set of proximal facies.

The thickness of the section is 55 m (Fig. 3). The Lecho Formation is composed of 15 m of a fining-upward succession of matrix supported conglomerates and coarse to fine sandstones. The clasts of conglomerates are angular and poorly sorted, product of debris flows in an environment with sparse water supply, probably alluvial fans. The upper part of the Lecho Formation is composed of coarse red sandstones with parallel stratification, which is suggested in the context of the section as caused by floodplain deposition. The contact with the Yacoraite Formation is transitional, and the thickness of this unit is about 40 m. The lithology is composed of limestones of different textures, with oolitic and intraclastic grainstones, oo-intraclastic packstones, wackestones, fine calcareous sandstones, limestones, mudstones and stromatolitic levels. The tracks studied here are found at the top of a yellowish wackestone-packstone. The facies arrangement is indicative of a lagoon with some tidal influence, in which the rates of sediment, water and accommodation space are in balance over the time span

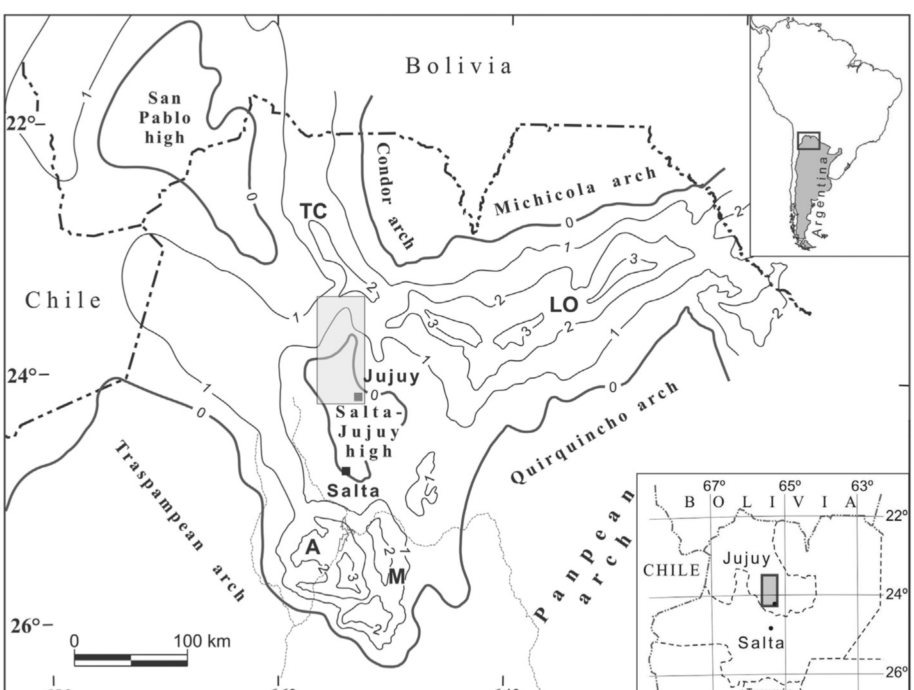

Fig. 1. Isopach map of the Yacoraite Formation, Argentina. Subbasins: TC, Tres Cruces; LO, Lomas de Olmedo; A, Alemanía; M, Metán; P, Pirity. Thickness in hundreds of metres. Inset: Location of the study area in the Tres Cruces Subbasins (after Marquillas et al., 2005, 2011).

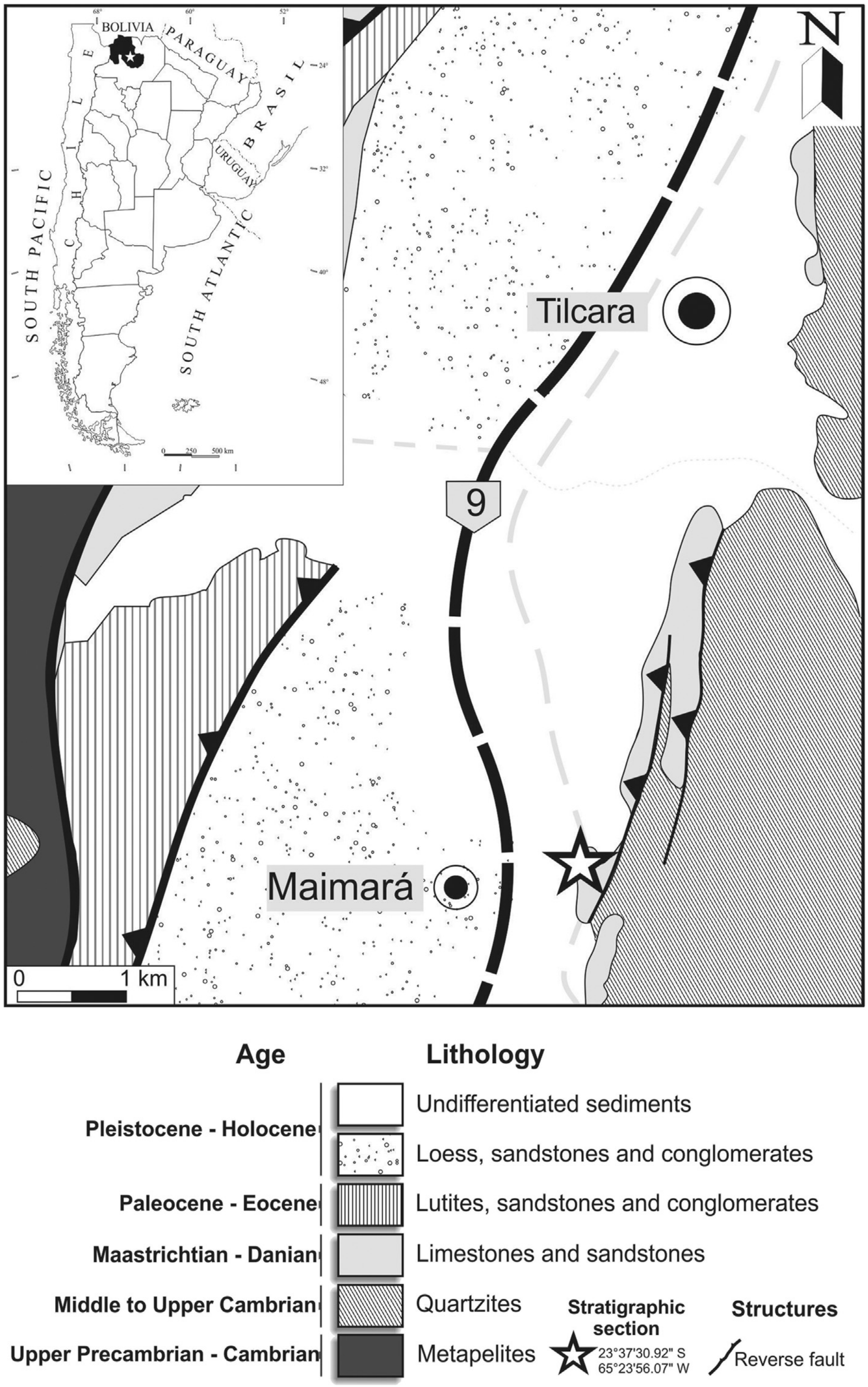

Fig. 2. Simplified geological map of the Maimará area on the southern Tres Cruces Subbasin.

of the sequence development. The water inflows are sufficient to periodically fill available accommodation, but they are not always balanced by outflow, that is common in balanced-fill lake basins (sensu Bohacs et al., 2000).

3. Material and method

This work analyses a trackway composed of four footprints and two possible hand prints. The track bearing slab was not collected. The tracksite was mapped and photographed *in situ*. Descriptions and measurements have been performed directly in first-hand examination of the specimens in the field and in photographs (sensu Leonardi, 1987; Thulborn, 1990; Pérez-Lorente, 2001).

Comments about the preservation of the tracks are based on the criteria of Thulborn (1990), Fornós et al. (2002), Romero-Molina et al. (2003) and Marty (2008). The ichnotaxonomic approaches

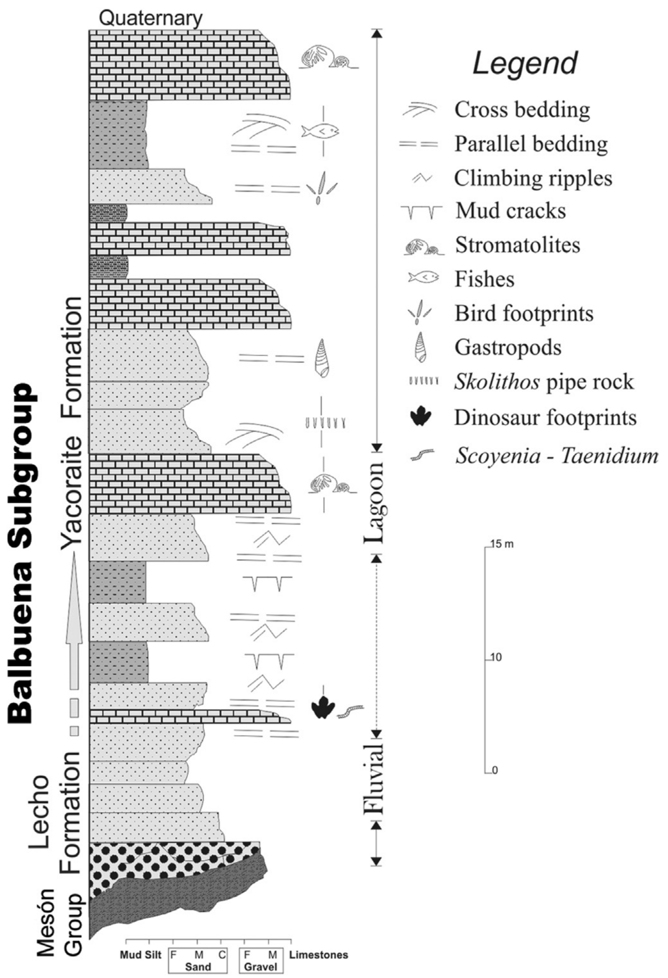

Fig. 3. Integrated stratigraphical column of the Balbuena Subgroup in Maimará, Tres Cruces Subbasin, Argentina.

Fig. 4. Photograph (A) and interpretative outline drawing (B) of the Maimará large ornithopod trackway. m?, probably manus track.

about large ornithopod tracks of Thulborn (1990), Lockley et al. (2003, 2014) and Díaz-Martínez et al. (2015) have been followed in this work.

4. Results

4.1. Track preservation

The studied tracks are at the top of a yellowish wackestone-packstone (layer 1 in Fig. 4). On the layer 1, other deformations not related with the large ornithopod tracks have been found. These deformations are probably undertracks of other dinosaur tracks (see Fig. 4). Except the footprint 1, which is the shallowest and is represented just by a very slight depression, the rest of the tracks have thin layers inside the hole of the tracks in the limestone. In the footprint 2, there are two deformed thin layers that show a laterovertical displacement (layers 2 and 3 in Fig. 4). Within the footprint 3, four thin layers can be identified (layers 2, 3, 4 and 5) inside. The layers 2, 3 and 4 are deformed and appear broken and vertically only close to the edge of the footprint. The layer 5 covers the footprint, which represents a sauropod footprint (sensu Cónsole-Gonella et al., 2012a, 2013). Finally, in the footprint 4 only the layer 4 is visible. The contour of the footprint is limited by this layer preserving structures of the dinosaur foot, as pads and claws. Based on the whole data, probably the trackmaker stepped over the layer 4, which would be the tracking surface (sensu Fornós et al., 2002), deforming this layer and the layers that were below. The footprints preserved in layers 1, 2 and 3 are undertracks (sensu Thulborn, 1990; Marty, 2008). In the layer 4, the footprints have been preserved as true tracks likely as underprints (sensu Thulborn, 1990; Romero-Molina et al., 2003; Marty, 2008). Finally, the layer 5 covers the footprints and is considered as an overtrack (sensu Marty, 2008).

4.2. Ichnotaxonomy

Ichnofamily Iguanodontipodidae Vialov, 1988 sensu Lockley et al., 2014.

Type ichnogenus: *Iguanodontipus* Sarjeant et al., 1998.

Other ichnogenera: *Caririchnium* Leonardi, 1984; *Hadrosauropodus* Lockley et al., 2003.

Diagnosis: Mesaxonic, tridactyl, subsymmetrical pes tracks that are as wide as or wider than long; one pad impression in each digit and one in the heel; digit pads longer than wide; well-developed notches in the proximal part of the digit II and IV impressions; manus tracks occasionally present and much smaller than the pes tracks (Díaz-Martínez et al., 2015, pp. 20–21).

Remarks: Originally, Vialov (1988) defined the ichnofamily Iguanodontipodidae but lacking a diagnosis. Recently, this ichnofamily has been re-studied by Lockley et al. (2014) and Díaz-

Martínez et al. (2015), and both proposed a different diagnosis for it. The main differences between these two papers are the ichnogenera that are included in the ichnofamily. On the one hand, Lockley et al. (2014) included within Iguanodontipodidae the Early Cretaceous ichnogenera *Amblydactylus*, *Caririchnium* and *Iguanodontipus*. On the other hand, Díaz-Martínez et al. (2015) included the Early and Late Cretaceous *Iguanodontipus*, *Caririchnium* and *Hadrosauropodus*. For us, the ichnogenus *Hadrosauropodus* shares the main features of both diagnosis and should be included within Iguanodontipodidae as suggested Díaz-Martínez et al. (2015). Therefore, this last ichnotaxonomical approach is followed here.

Hadrosauropodus Lockley et al., 2003.

Type ichnospecies: *Hadrosauropodus langstoni* Lockley et al., 2003.

Other ichnospecies: *Hadrosauropodus leonardii* (Lockley, 1987); *Hadrosauropodus kyoungsookimi* (Lim et al., 2012).

Diagnosis: Tracks belonging to Iguanodontipodidae with a large heel impression that is bilobed, centred and wide (wider than the width of the proximal part of the digit III impression); pad of digit III shorter than those of digits II and IV; short, wide digit impressions with blunt distal ends (Díaz-Martínez et al., 2015, p. 32).

Remarks: Lockley et al. (2003) defined the ichnotaxon *Hadrosauropodus* on the basis of the large ornithopod tracks with bilobed heel impression and short, wide digit impressions from the Maastrichtian of Canada. Díaz-Martínez et al. (2015) emended the original diagnosis in order to homogenize the comparison with the others ichnogenera of Iguanodontipodidae. The heel and digit shape impressions allow distinguishing among *Hadrosauropodus*, *Caririchnium* and *Iguanodontipus* (sensu Díaz-Martínez et al., 2015). *Hadrosauropodus* presents a wide and bilobed heel impression and wide and short digit impressions, while *Iguanodontipus* is characterized by a small and rounded heel and elongate, narrow digit impressions, and *Caririchnium* has a large, rounded heel and short, wide digit impressions. This suggestion is followed here.

Hadrosauropodus isp. (Figs. 4 and 5).

Material: at least a footprint integrating a four track trackway, with probably two associated hand prints.

Description: The trackway is composed of four footprints and probably two associated hand prints, most of them differently preserved. The footprint 1 is very shallow and only displays the proximal surface. The footprint 2 is longer than wide (45 cm long, including a likely elongate metatarsal impression, and 28 cm wide), depth and with short and width toe impressions. Inside the second footprint two deformed thin layers are preserved. The shape of the footprint 3 is not very clear because is filled by four different thin layers. Its length is 32 cm and shows short and wide toe impressions. The footprint 4 is better-preserved than the others. It is tridactyl, mesaxonic, longer than wide (36 cm long, including the digit III claw trace, and 28 cm wide), with a wide bilobed heel. The heel pad impression measures 19 cm in the maximum width and 15 cm of maximum length. The digit impressions, composed of a pad and claw trace, are longer than wide. The impression of digit III is subtriangular and measures 19 cm wide and 16.5 cm long. Its pad impression is wider than long (17 cm wide and 15 cm long) and also its claw trace (8.5 cm wide and 4.5 cm long), which is hoof-like and is impressed separately of the pad. Digit II impression is elliptical to tear-drop and measures 15 cm long and 7 cm wide. The pad impression is longer than wide (12 cm long and 7 cm wide). The claw trace, of 4 cm long and 5 cm wide and connected with the pad impression, is hoof-like. Digit IV impression is elliptical to tear-drop and measures 16 cm wide and 7 cm long. The pad is longer than wide (12.5 cm long and 6 cm wide). The claw trace, with a hoof-like shape, is located independently of the pad and is twice wider than long (6 cm and 3 cm respectively). Digit III impression protrudes farther anteriorly than II and IV impressions. Digit II and IV impressions are oriented sub-parallel to digit III (divarication between II-III 13° and between III-IV 16°). The footprint presents symmetrical indentations separating the posterior margin of the lateral digits and the heel pad.

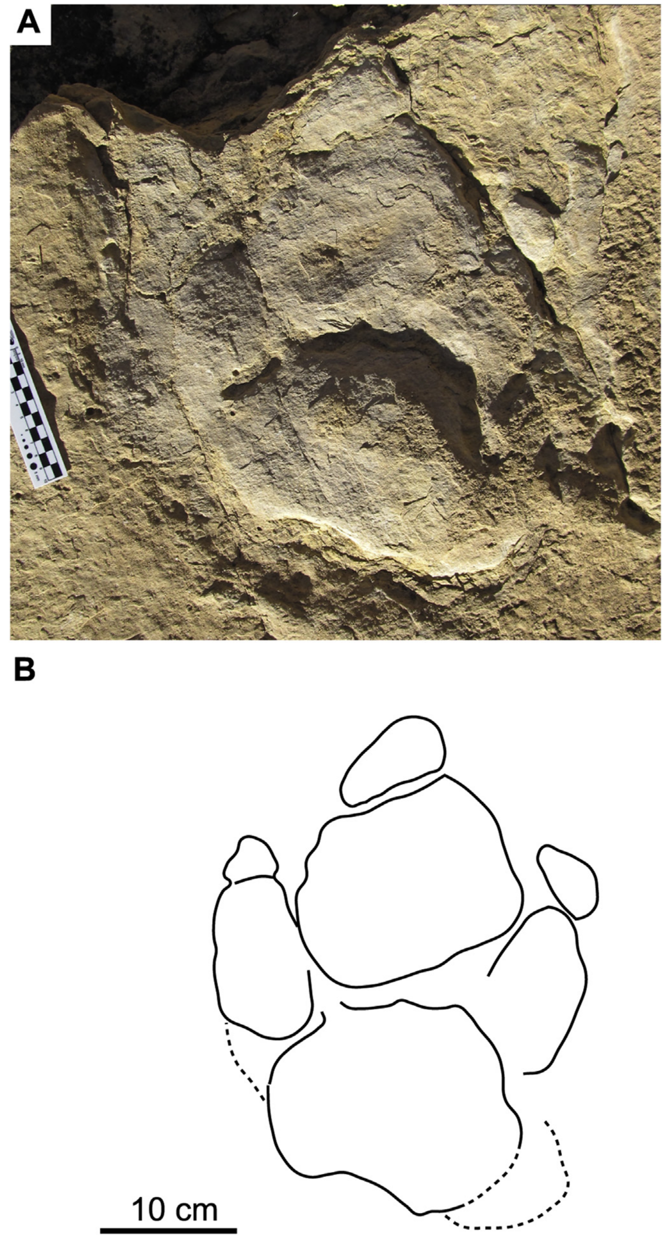

Fig. 5. Photograph (A) and interpretative outline drawing (B) of Hadrosauropodus.

In front of the footprints 2 and 3 there are possible manus tracks, located laterally between the digits III and IV impressions. These manus prints are much smaller than the footprints and wider than long (one is 4 cm long and 5 cm wide, the other is 6 cm long and 9 cm wide). The best-preserved manus track is near the third footprint and is somewhat rounded, but with a slight transverse elongation. It is bilobate with the lobes different in size, the internal lobe being smaller than the external one.

The pace length (for the pes tracks) is short, 50 cm between footprints 1 and 2, 40 cm between footprints 2 and 3, and 41 cm between footprints 3 and 4. The stride length is about 44 cm for the footprints 1 and 3, and 47 cm for footprints 2 and 4. Finally, the pace angulation is of 58° among footprints 1, 2 and 3, and of 70° among footprints 2, 3 and 4.

Remarks: The track 4 (Fig. 4) is the best preserved of the studied trackway. It is tridactyl, mesaxonic, subsymmetrical, with one pad impression in each digit and one in the heel, and presents well-developed notches in the proximal part of the digit II and IV impressions. These characters justified the inclusion in Iguanodontipodidae. This ichnofamily is composed of the ichnotaxa *Iguanodontipus*, *Caririchnium* and *Hadrosauropodus* (sensu Díaz-Martínez et al., 2015). These authors considered that the shape of the heel and digit impressions allow to distinguish the three ichnogenera of Iguanodontipodidae. *Iguanodontipus* is characterized by a narrow, rounded heel, and long, narrow digit impressions. In contrast, *Caririchnium* has a wide, rounded heel, and short, wide digit impressions, while *Hadrosauropodus* shows a wide, bilobed heel, and short, wide digit impressions. These last features are present in the studied track and therefore we assign it to *Hadrosauropodus*.

Díaz-Martínez et al. (2015) proposed three valid ichnospecies within *Hadrosauropodus*, namely *H. langstoni*, *H. leonardii* and *H. kyoungsookimi*. These authors stated that the width of the heel, the position of the notches and the manus impression are useful ichnotaxobases to differ among ichnospecies. *H. langstoni* is mainly characterized by having a very wide heel impression. Moreover, the notches of the impressions of the digits II and IV are positioned far back, close to the proximal part of the heel. The others ichnospecies of *Hadrosauropodus* show a narrower heel and the notches of digits II and IV imprints are close to the proximal part of the digit III pad impression. On the other hand, the manus tracks of *H. langstoni* are different (triangular) from those of *H. leonardii* (rectangular) and *H. kyoungsookimi* (crescent-shaped). In the specimen from Maimará, the heel of the well-preserved track is a little deformed, and the possible manus tracks are very shallow and have different shapes as it has been previously detailed. Therefore, we assigned these tracks to *Hadrosauropodus* isp.

5. Discussion

The presence of uppermost Cretaceous large ornithopod tracks, also called "hadrosaur tracks" (e.g., tridactyl, mesaxonic tracks, lengths of digits II, III, and IV subequal; wide digits with rounded ends; digits converge proximally into a broad metatarsophalangeal impression or 'heel pad'; similar in anteroposterior and mediolateral dimensions; general shapes as a clover; sensu Moreno et al., 2012), in Gondwana is limited to four sites in South America. This ichnological record is located in Argentina (Alonso, 1980; Alonso and Marquillas, 1986), Peru (Jaillard et al., 1993) and possibly Bolivia (Lockley et al., 2002), and it is scarce if it is compared with the record from Laurasia (see Vila et al., 2013, and references therein). In Argentina, Alonso (1980) and Alonso and Marquillas (1986) defined three ichnotaxa from the Yacoraite Formation, originally related with hadrosaurid trackmakers: *Hadrosaurichnus australis* Alonso, 1980, *Taponichnus donottoi* Alonso and Marquillas, 1986, and *Telosichnus saltensis* Alonso and Marquillas, 1986. On the basis of a trackway composed of five footprints from outcrops of the Vilquechico Group (Campanian-Maatrichtian) of Peru, Jaillard et al. (1993) erected the ichnospecies *Hadrosaurichnus titicaensis*. The authors related it with hadrosaurid trackmakers mainly because of some ornithopod features and the age of the level where they were found (i.e., Campanian–Maastrichtian).

For instance, short digit impressions and interdigital web traces have been mentioned as features of *H. australis*, *H. titicaensis* and *T. donottoi*. The problem is that there is no evidence of an interdigital web in the ornithopod foot (Lockley et al., 2003), and both the above mentioned features may be the result of extramorphological factors. Besides, the tracks of all of these ichnotaxa are not well-preserved (see Díaz-Martínez et al., 2015) and the ornithopod affinity of *H. australis* is questioned (Lockley et al., 2003). On the other hand, Lockley et al. (2002) cited from the El Molino Formation (Maastrichtian-Danian), Bolivia, some tracks that may be attributed to non-theropodan bipeds such as ornithopods; as occurs with ankylosaurs, and ornithischians in general, skeletal records of ornithopods are rare in South America. Therefore, the ornithopod affinity of these tracks is not clear.

The tracks from Maimará are different from the others possible large ornithopod tracks of South America. They are the unique with bilobed heel impressions, one pad impression in the heel and one in each digit imprint, and clear blunt claw traces. Lockley et al. (2003) suggested that large ornithopod tracks of South America were scarce and of an uncertain nature. The previously cited tracks from Argentina, Peru and Bolivia are not well preserved and the presence of large ornithopod tracks in South America was not clear. Therefore, the Maimará tracks represent the unambiguous presence of large ornithopod tracks in the uppermost Cretaceous of Gondwana.

Until now, *Hadrosauropodus* had a wide Laurasia distribution known in North America, Asia and Europe (e.g., Lockley et al., 2003; Xing et al., 2009; Vila et al., 2013; Díaz-Martínez et al., 2015). This ichnogenus have been cited from the Aptian Jindong Formation, Korea (Huh et al., 2003; Lim et al., 2012), from the Aptian-Albian Gething Formation, Canada (Currie, 1995; McCrea, 2000), from the upper Albian Pajarito Formation, USA (Hunt and Lucas, 1998), from the Albian-Cenomanian Dakota Group, USA (e.g., Lockley, 1987; Currie et al., 1991; Schumacher, 2003), from the Albian-Cenomanian Mojado Formation, USA and Mexico (Kappus et al., 2011), from the Campanian Menefee Formation, USA (Hunt and Lucas, 2006), from the Campanian Mesa Verde Group, USA (Carpenter, 1992), from the late Campanian or early Maastrichtian Cantwell Formation, USA (Fiorillo et al., 2014), from the late Campanian-early Maastrichtian Wapiti Formation, Canada (McCrea et al., 2014), from the Maastrichtian Lance Formation, USA (Lockley et al., 2003), from the Maastrichtian St. Mary River Formation, Canada (Lockley et al., 2003), from the Maastrichtian Zhutian Formation, China (Xing et al., 2009), and from the Maastrichtian Tremp Formation, Spain (Vila et al., 2013). So, the Maimará tracks are the first evidence of *Hadrosauropodus* in Gondwana, and consequently expand the geographic range of this ichnogenus to South America (see Table 1; Fig. 6).

The Late Cretaceous large ornithopod tracks are commonly related with hadrosaurid dinosaurs (e.g., Fanti et al., 2013; Fiorillo et al., 2014). This relationship is mainly based on the age (the tracks are in a temporal range when hadrosaurid bones are known), the geography (the tracks are in a geographic region with hadrosaurid remains) and the fossil association (the tracks are in levels where hadrosaurid bones have been found) (sensu Thulborn, 1990). Other researchers have proposed an osteological correlation between hadrosaurid tracks and trackmakers (Currie, 1983; Thulborn, 1990; Carrano and Wilson, 2001). Nevertheless, these osteological features not always are easily recognizable in the tracks. Large ornithopod tracks are in general simple in shape. They are tridactyl, mesaxonic, with hoof-like claw traces and one pad impression in each digit and another one in the heel. Moreno et al. (2007) described the pedal morphology of hadrosauriform dinosaurs (sensu Horner et al., 2004). Some features could be recognizable in the tracks, such as tridactyly (tridactyl tracks), distal phalanges with hoof-shape (digit impressions with blunt distal ends), and phalanges wider and dorsoventrally thinner than long (wide digit impressions). Recently, Llandrés-Serrano et al. (2013) have studied a pes with soft tissue preserved on a specimen referred to the basal hadrosauriform *Mantellisaurus* Paul, 2006. These authors identified two types of integumentary structures that may correspond with the hoof-like claws close to the ungual tips and with the toe pads

Table 1
Geographical and temporal distribution of Campanian-Maastrichtian Hadrosauropodus tracks. The tracks have been determined sensu Díaz-Martínez et al. (2015).

Ichnotaxon	Lithostratigraphic unit	Age	Locality	Original reference
Hadrosauropodus isp.	Menefee Formation	Upper Santonian- Lower Campanian	New Mexico (USA)	Hunt and Lucas (2006)
Hadrosauropodus isp.	Mesa Verde Group	Campanian	Colorado-Utah- Wyoming (USA)	Carpenter (1992)
Hadrosauropodus langstoni	St. Mary River Formation	?Campanian-Maastrichtian	Alberta (Canada)	Lockley et al. (2003)
Hadrosauropodus isp.	Wapiti Formation	Upper Campanian-Lower Maastrichtian	Alberta and British Columbia (Canada)	Fanti et al. (2013); McCrea et al. (2014)
Hadrosauropodus isp.	Cantwell Formation	Upper Campanian-Lower Maastrichtian	Alaska (USA)	Fiorillo et al. (2014)
Hadrosauropodus isp.	Lance Formation	Maastrichtian	Wyoming (USA)	Lockley et al. (2003)
Hadrosauropodus isp.	Tremp Formation	Maastrichtian	Pyrenees (Spain)	Suñer et al. (2008); Vila et al. (2013)
Hadrosauropodus isp.	Zhutian Formation	Maastrichtian	Guangdong (China)	Xing et al. (2009)
Hadrosauropodus isp.	Yacoraite Formation	Maastrichtian- Danian	Jujuy (Argentina)	In this work

around each digit. These last two features could be related with the hoof claw traces and with the unique pad impression that are present in each digit in large ornithopod tracks. This could mean that the main features of the large ornithopod tracks are present in at least the clade Hadrosauriformes, although some of them (i.e., distal phalanges with hoof-shape and phalanges wider and dorsoventrally thinner than long) might be identifiable in more basal ornithopod clades, such as Styracosterna (see *Hippodraco* McDonald et al., 2010). As the unique members of hadrosauriforms present in the latest Cretaceous are the Hadrosauridae (sensu McDonald, 2012), we consider that is more parsimonious to relate the *Hadrosauropodus* of Maimará with hadrosaurid dinosaurs. However, the data currently available do not allow confident identification of the trackmaker on the basis of morphological features (Díaz-Martínez et al., 2015).

Compared with Laurasia, the hadrosaurid bone remains found in Gondwana are scarce. Up to date, this record is limited to three geographic areas: Patagonia and La Pampa province, both in South America (Coria, 2014; and references herein; Cruzado-Caballero, 2014), and Antarctica (Otero and Reguero, 2013, and references therein). In Patagonia and La Pampa province, the hadrosaurid bones bearing formations are: Bajo Barreal/Laguna Palacio, Angostura Colorada/Coli-Toro, Los Alamitos, and Allen. These geological units are considered as Campanian-Maastrichtian in age and seem to be correlatable, and thus correspond to a related series of depositional events that took place within a short temporal interval (Coria, 2014). The bones remains have been related to Hadrosauridae indet (Casamiquela, 1964; Apesteguía and Cambiaso, 1999; Hill et al., 2002; Luna et al., 2003; Martinelli and Forasiepi, 2004; Cruzado-Caballero, 2014; Cruzado-Caballero and Coria, 2014), with the basal hadrosaurid *Secernosaurus koerneri* (Bonaparte et al., 1984; Prieto-Márquez and Salinas, 2010) and *Lapampasaurus cholinoi* (Juárez-Valieri et al., 2010; Coria et al., 2012), and the hadrosaurine *Willinakaqe salitranensis* (Juárez-Valieri et al., 2010; Coria, 2014). In Antarctica, hadrosaurids are limited to the Maastrichtian López de Bertolano Formation (Otero and Reguero, 2013). The fossil remains are fragmentary and scarce and were classified as Hadrosauridae indet (Rich et al., 1999; Case et al., 2000; Otero and Reguero, 2013).

If the trackmaker of the *Hadrosauropodus* tracks from Maimará is a member of Hadrosauridae, this work contributes adding a new locality to the scarce Gondwana record. Besides, taking into account that the earliest locality with hadrosaurid remains is 1500 km to south of Maimará in the La Pampa province (Coria et al., 2012), this find would be the most northerly record in Argentina, or in Gondwana if we consider that the other ornithopod tracks described in Argentina, Peru and Bolivia do not show unambiguous hadrosaurid features, expanding the distribution of this clade.

Finally, in terms of the chronostratigraphy of the Yacoraite Formation, this record is relevant considering the work of Sial et al. (2001). These authors have identified the K-Pg transition in the same locality, although unfortunately the paper not provides the detailed position of the stratigraphic section. However, it is possible to assume that the level of the *Hadrosauropodus* tracks corresponds

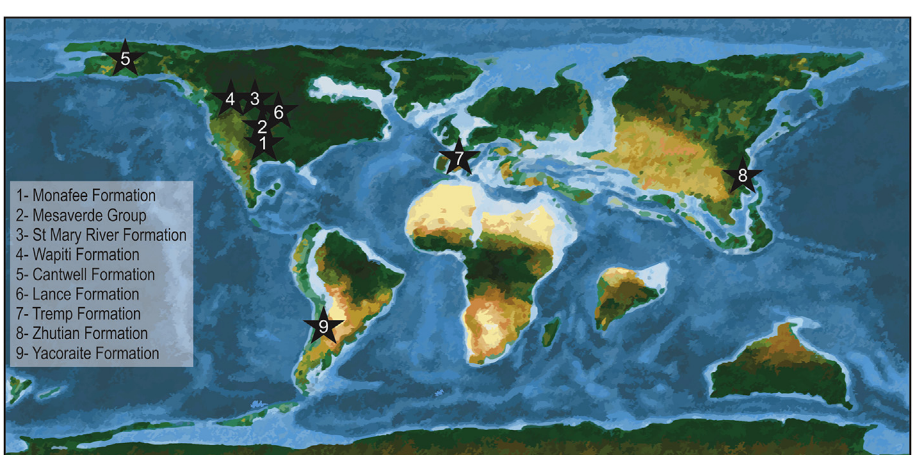

Fig. 6. Palaeobiogeographic distribution of Campanian-Maastrichtian Hadrosauropodus tracks. More information in Table 1. Palaeogeographic map modified from reconstructions by Ron Blakey, NAU Geology (http://jan.ucc.nau.edu/~rcb7/065Marect.jpg).

to the Late Maastrichtian, and that the K-Pg transition it is present in the upper part of the section. The study of the relationship between the K-Pg transition and the dinosaur tracks in this stratigraphic section is suggestive to further work.

6. Conclusions

A new quadrupedal dinosaur trackway has been found in the Yacoraite Formation (Masstrichtian-Danian), in the Maimará site, in the northwestern of Argentina. The best preserved track is tridactyl, mesaxonic, longer than wide, with a wide bilobed heel, one pad impression in each digit and one in the heel, wide digit impressions and blunt claw marks. On the basis of these features, the Maimará tracks document the unambiguous presence of large ornithopod tracks in the uppermost Cretaceous of Gondwana. Besides, the main features of these tracks are diagnostic of the ichnogenus *Hadrosauropodus*, although the preservation of the tracks is not good enough to assign them to a concrete ichnospecies. This record represents the first evidence of *Hadrosauropodus* in Gondwana, expanding the geographic range of this ichnogenus that before this work was exclusively known in Laurasia.

Finally, if it is considered a member of Hadrosauridae as the trackmaker of the *Hadrosauropodus* tracks found in Maimará, this record thus represents the most northerly evidence of hadrosaurids in Argentina.

Acknowledgements

We thank the editors of this special volume and the organization of the 3rd Young Earth Scientists Congress (Tanzania, 2014). We also thank Penélope Cruzado-Caballero for their comments on an early version of the manuscript. We are grateful to colleagues Rosa Marquillas, Ma. Cristina Sánchez, Patricio Herrera and Pablo Machuca, for their help in different stages of the fieldwork. Xabier Pereda-Suberbiola and Ismar de Souza Carvalho made valuable comments that greatly improved the paper.

This research was supported by grants PICT 1665 of the Agencia Nacional de Promoción Científica y Tecnológica (C. Cónsole-Gonella), PIP 0053 of the Consejo Nacional de Investigaciones Científicas y Técnicas and PI UNRN 40-A-402 of the Universidad Nacional de Río Negro (S. de Valais), CIUNSa 2043 of the Universidad Nacional de Salta (R. Marquillas), IT834-13 of the Basque Government (Humberto Astibia), and CGL2013-47521-P of the MINECO of the Ministerio de Economía y Competitividad of Spain (Ainara Badiola).

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