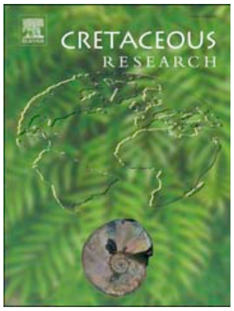

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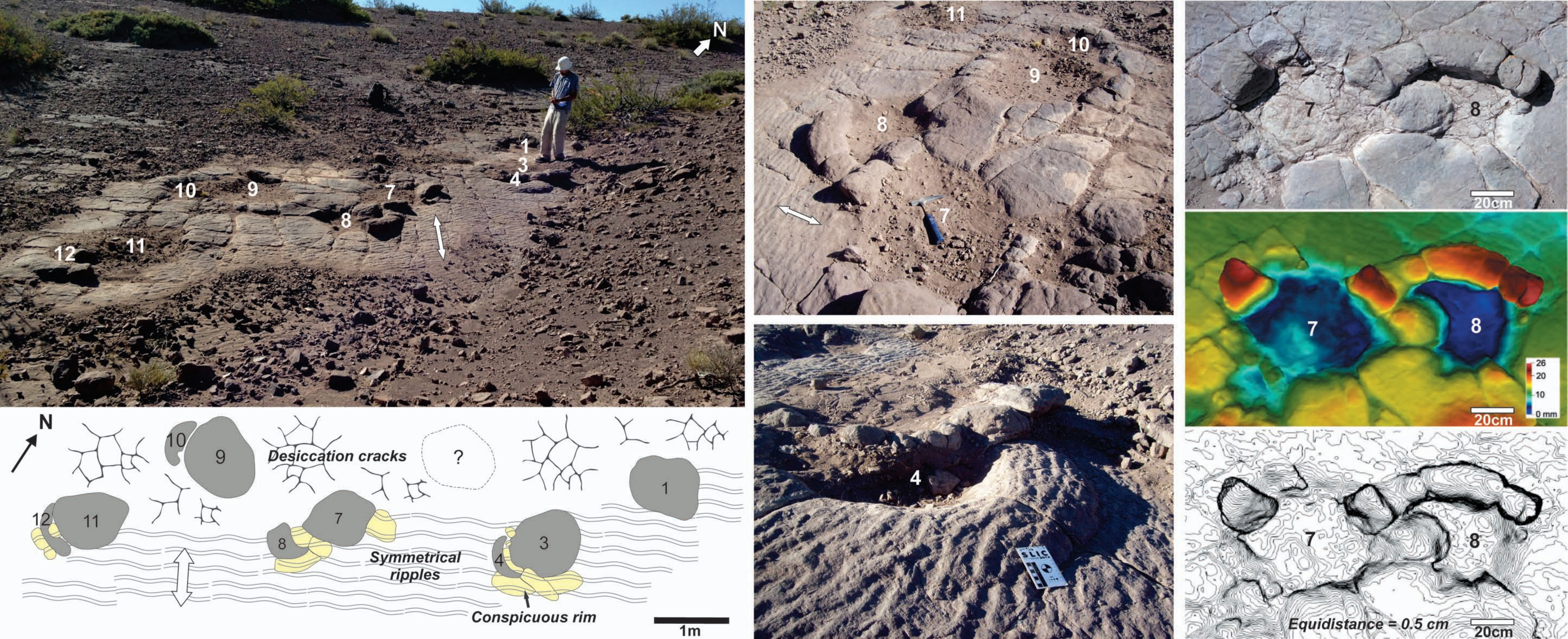
N
1
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12
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Desiccation cracks
?
1
12
11
7
8
3
4
Symmetrical ripples
Conspicuous rim
1m
11
10
9
8
7
4
SLIC
7
8
20cm
7
8
26
20
10
0 mm
20cm
7
8
Equidistance = 0.5 cm
20cm

A new narrow-gauge sauropod trackway from the Cenomanian Candeleros Formation, northern Patagonia, Argentina

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ABSTRACT

Dinosaurs are extremely abundant in the Upper Cretaceous Neuquén Group of the Neuquén Basin (Argentina). Nevertheless, while osteological remains are rich the ichnological record is more restricted. A new sauropod dinosaur trackway with five manus-pes imprint sets discovered in the Cenomanian Candeleros Formation is described here. The trackway belongs to the narrow-gauge type that is identified for the first time in the Cenomanian and possibly for the Late Cretaceous. It is preserved as concave epirelief in fine-grained sandstones from floodplain deposits. The tracks, which are large in size (average length of 98 cm), include conspicuous rims with very well-preserved symmetrical ripples on top that are documented for the first time in the track record. Due to their preservation and the absence of clear anatomical details, the trackway was not assigned to any particular ichnotaxon. Taking into account the presence of rebbachisaurid diplodocoid remains in the Candeleros Formation, the classical association of narrow-gauge trackways with diplodocoids and the inferred gleno-acetabular distance, it is suggested that the studied trackway might belong to a large-sized rebbachisaurid. The worldwide record of Cenomanian dinosaur tracks includes only a few records of sauropod tracks. Thus, this new

finding contributes to increase the knowledge about the early Late Cretaceous sauropods and their tracks.

Key words: Sauropod footprints; Narrow-gauge trackway; Rebbachisauridae; Upper Cretaceous; Neuquén Basin

1. Introduction

In regard to its vertebrate record, the Cretaceous continental deposits in the Neuquén Basin are some of the most fossiliferous and stratigraphically complete worldwide. In this basin, most of the tetrapod record was found in Upper Cretaceous deposits, including a high diversity of saurischian and ornithischian dinosaurs, while the Lower Cretaceous remains are scarcer (Leanza et al., 2004).

Among the sauropods of South America, the clade Titanosauriformes is the best represented (Otero and Salgado, 2015). In the Upper Cretaceous of Neuquén Basin their record includes the most basal titanosaurid *Andesaurus delgadoi* Calvo and Bonaparte, 1991, one of the largest dinosaurs in the world *Argentinosaurus huinculensis* Bonaparte and Coria, 1993, the small-sized saltasaurine *Neuquensaurus australis* Powell, 1992 and several titanosaurid eggs containing delicate remains of embryos (Chiappe and Coria, 2004) among others. Also in the Upper Cretaceous of Neuquén Basin the clade Diplodocoidea is well represented, specifically by Rebbachisauridae including *Limaysaurus tessonei* (Calvo and Salgado, 1995), *Rayososaurus agrioensis* Bonaparte, 1966, and *Cathartesaura anaerobica* Gallina and Apesteguía, 2005.

The dinosaur ichnological record in the Neuquén basin is scarcer than the osteological one. In the Lower Cretaceous, there are only two units with dinosaur tracks: the Agrio Formation (Hauterivian–Barremian) with theropod tracks (Pazos et al., 2012), and the Rayoso Formation (Albian), where sauropod trackways were assigned to rebbachisaurid diplodocids (Canudo et al., 2017). Conversely, in the Upper Cretaceous, dinosaur tracks are more abundant: theropod, ornithopod and sauropod tracks have been reported from the Cenomanian Candeleros Formation (Calvo, 1991, 1999; Calvo and Mazzetta, 2004; Candia Halupczok et al., 2018; Calvo and Rivera, 2018), theropod and sauropod tracks from the lower Campanian–upper Campanian Anacleto Formation (Coria et al., 2002; Paz et al., 2014; Díaz-Martínez et al., 2018) and sauropod tracks from the upper Campanian–lower Maastrichtian Loncoche and Allen formations (González Riga and Calvo, 2009; Díaz-Martínez et al., 2018; González Riga and Tomaselli, 2018). Huene (1931) documented a theropod track from the Upper Cretaceous of the Neuquén Basin in the locality of Plottier (Neuquén Province), but without a precise lithostratigraphic position. Considering the outcrop distribution of the Neuquén Group (Garrido, 2010), this record might belong to the Turonian–Santonian Río Neuquén Subgroup. Taking into account the published data, the Candeleros Formation presents the highest ichnodiversity from the Neuquén Basin and includes: titanosaur sauropod tracks referred to *Sauropodichnus giganteus* Calvo 1991, iguanodontid tracks (*Sausaichnium monettae* Calvo, 1991 and *Limayichnus major* Calvo, 1991), other ornithopod tracks (*Bonaparteichnium tali* Calvo, 1991), several theropod tracks (*Abelichnus astigarrae* Calvo, 1991, *Bressanichnus patagonicus* Calvo, 1991, *Deferrariischnium mapuchensis* Calvo, 1991, *Picunichnus benedettoi* Calvo, 1991, *Candeleroichnus canalei* Calvo and Rivera, 2018), the first pterosaur tracks reported from Gondwana assigned to *Pteraichnus* Stokes, 1957, by Calvo and Lockley (2001), different tracks ascribed to carnosaurs and coelurosaurs (Calvo and Mazzetta, 2004), and poorly preserved tracks attributed to theropods or iguanodontians (Candia Halupczok et al., 2018). The only Late Cretaceous sauropod tracks known in the basin besides the ones from Candeleros Formation, come from the Loncoche Formation (upper Campanian–lower Maastrichtian) where another sauropod ichnotaxon, *Titanopodus mendozensis* González Riga and Calvo, 2009, was identified (González Riga and Calvo, 2009; González Riga, 2011; González Riga and Tomaselli, 2018). While Cenomanian dinosaur tracks are relatively abundant worldwide (e.g., Lockley et al., 2014 and references herein; Romilio and Salisbury, 2014), there are only a few records of sauropod tracks from the Cenomanian (Calvo, 1991; Mezga and Bajraktarević, 1999; Dalla Vecchia et al., 2001; Ibrahim et al., 2014).

The analysis of track preservation can yield important information on substrate conditions at the time of track formation (Thulborn, 1990). One important source of evidence is the displacement rims around tracks, which can indicate the level of consistency and moisture within the substrate. The recognition of the sediment surface on which the trackmaker leaves its tracks ("tracking surface" sensu Fornós et al., 2002) is key for the characterization of the substrate conditions on that surface (Lockley 1991). Both substrate properties and track preservation (if they are true tracks or undertracks) may exert significant influence in sauropod trackway gauge (Castanera et al., 2012).

In this study, a new tracksite from the Cenomanian Candeleros Formation, located to the northwest of the previously studied tracks of the unit is analysed. The aim of this paper is fourfold: i) to describe morphologically in detail a new sauropod trackway; ii) to examine the substrate conditions and depositional setting related to the track preservation; ii) to provide an ichnotaxonomical analysis focused in the main narrow gauge ichnotaxa and compare this record with similar sauropod tracks from the Cenomanian worldwide; and, iv) to discuss the possible trackmaker and their paleobiological implications.

2. Geological setting

The Neuquén basin is located mainly in the eastern flank of the Andean mountain range in Argentina between 32 ° and 40 ° S latitude (Fig. 1a). It covers an area of about 120,000 km² and comprises a continuous stratigraphic record of more than 7000 m in thickness (Legarreta and Gulisano, 1989; Yrigoyen, 1991; Howell et al., 2005). The sedimentary fill record comprises an Upper Triassic to lower Cenozoic succession that includes volcaniclastic, siliciclastic, carbonates and evaporites deposited in marine and continental environments. The Neuquén basin records a complex tectonic evolution, starting with an initial rift stage in the Late Triassic–Early Jurassic, followed by a thermal subsidence regime in a retroarc setting during Middle Jurassic–Early Cretaceous, and ending as a foreland basin system in the Late Cretaceous–Paleogene (Manceda and Figueroa 1995; Howell, et al., 2005; Tunik et al., 2010; Naipauer and Ramos, 2016). The beginning of the foreland stage is characterized by the accumulation of more than 1000 m of fluvial, aeolian and shallow lacustrine deposits, included in the Cenomanian-Campanian Neuquén Group (Stipanicic et al., 1968; Garrido, 2010; Fennell et al., 2017).

Garrido (2010) proposed a new stratigraphical framework of the Neuquén Group, where the Río Limay Subgroup (De Ferraríis, 1968) is the basal subdivision of the group (Fig. 1b) and includes the Candeleros and the Huincul formations (Garrido, 2010). The Candeleros Formation that was originally defined as the “Candeleros Group” by Keidel (1917) was later redefined as Candeleros Formation by Di Paola (1973). The type locality of the unit is located to the east of the Lotena hill in the south of the Neuquén Province (Fig. 1a). This unit, characterized by typical red beds, is considered Cenomanian in age (Leanza et al., 2004, and references therein) corroborated by U–Pb detrital zircons ages (Tunik et al., 2010; Di Giulio et al., 2012, 2015).

The Candeleros Formation is composed of massive coarse- to medium-grained sandstones and conglomerates, with intercalations of thin siltstone beds, and exhibits a multiplicity of paleoenvironments which are related to its location within the paleogeographical context of the Neuquén Basin. In the type locality, about 200 km to the SSW of the area studied here, the unit was interpreted by Garrido (2010) as a fluvial system with braided and meandering regimes associated with muddy floodplain deposits and paleosoils. In order to show such paleoenvironmental diversity of the unit, other areas previously studied (Fig. 1a) are included in this paper. The area near to the Quilil Malal locality around the Agrio River is characterized by a meandering fluvial system with alluvial plains and fluvial-aeolian interactions (Gazzera and Spalletti, 1990). Aeolian deposits are also present with the highest thicknesses towards the southeast area of the Huincul high, including the Kokorkom paleodesert (e.g. Candia Halupczok et al., 2018). Moreover, aeolian and playa-lake deposits were documented on the southeastern border of the basin in the El

Chocón area (Spalletti and Gazzera, 1994). Close to the eastern limit of the Agrio Fold and Thrust Belt around the Colorado River, the unit is represented by a terminal fan system (Sánchez et al., 2008; Sánchez and Asurmendi, 2015). Whereas, the unit in the locality treated in this paper was not studied before.

The ichnological record of the Candeleros Formation in the Neuquén Province is well constrained to the border of the basin (easternmost outcrops), where sauropod tracks are known from the locality of El Chocón in the west coast of the Ezequiel Ramos Mexía dam (Calvo, 1991). The new tracksite studied in this work (Fig. 1a) is located in the westernmost outcrops of the Candeleros Formation (GPS point for reference: 37°26′43″ S, 69°54′2″ W), close to the area known as Aguada de Tuco, and next to the Provincial road 7, between Chos Malal and Añelo cities.

3. Materials and methods

The material was photographed and measured *in situ*. The measurements and terminology used in the present work are mainly based on the criteria of Leonardi (1987), Romano et al. (2007) and Marty (2008). The measurements were taken as shown in Figure 2: length (L) and width (W) of pes (p) and manus (m), pace angulation (ANG) and width of the angulation pattern (WAP). The length and width of sauropod tracks were measured inside the rims. The manus-pes distance (Dm-p) was not taken into account because in nearly all cases, the pes tracks overlap the manus ones. The exception is set 7-8 in which the manus-pes distance is practically equivalent to the manus length. The heteropody (H) was calculated with the manus-pes ratio as the (manus imprint area / pes imprint area) × 100 (Lockley et al., 1994a). These areas were obtained using the public domain java-based image processing program ImageJ. The heteropody index (HI) was used as [(LxW manus) / (LxW pes)] x 100 (González Riga and Calvo, 2009). H and HI were compared (see track description for more detail). In addition, to quantify the trackway gauge, the pes trackway ratio (PTR) was calculated following the indices proposed by Romano et al. (2007) as PTR =

(FW/eTW) × 100. The PTR range of values for wide-, medium- and narrow-gauge trackways is ≤35%, 36–49% and ≥50%, respectively. Also, the ratio between the width of the angulation pattern and the corresponding track length (WAP/PL) *sensu* Marty (2008) was calculated. The WAP/PL range of values for wide-, medium- and narrow-gauge trackways is ≥1.2, 1–1.2 and ≤1, respectively.

The preservational terminology: true track, elite track, underprint and undertrack are based on the criteria of Thulborn (1990), Lockley (1991), Lockley and Meyer (2000) and Marty et al. (2009). To determine the trackmakers, the phenetic, geographic-temporal and phylogenetic correlation approach Carrano and Wilson (2001) was followed.

The photogrammetric models (Falkingham, 2012; Mallison and Wings, 2014) have been obtained using Agisoft PhotoScan (version 0.8.5.1423), with the aim of studying the track morphology through 3D models, depth maps and contour lines. This method provides for an accurate study of the print depths and the distinction of internal and external track features, which are not easily discernible using traditional methods. Photogrammetric models were also imported into Meshlab for scaling and Paraview to generate depth and contour maps. The photogrammetric model was included in the supplementary materials.

The logged section analyzed here (1:100) comprises the lowermost part of the Candeleros Formation (Fig. 3). The beginning of the studied interval corresponds to a basal erosive surface that represents a regional angular unconformity (e.g. Tunik et al., 2010) between continental red mudstones of the Rayoso Formation below and fluvial conglomerates above it. The top of the logged section was delimited arbitrarily 8 m above the trackway-bearing level. In this work, the new trackway will be referred to as the Aguada de Tuco trackway. The stratigraphic divisions used in this paper follow the ICS International Chronostratigraphic Chart 2017 (Cohen et al., 2013, updated).

4. Sedimentological framework

In the studied area, the Candeleros Formation presents well-exposed outcrops, uniformly dipping 7–11 ºS. The studied interval is represented by reddish mudstones and siltstones, and brown to dark grey sandstones and subordinate fine-grained conglomerates. The logged section is subdivided in a lower interval, about 12 m thick, that contains a great proportion of fine-grained conglomerates and muddy siltstones, and an upper interval, about 24 m thick, where amalgamated sandstones with channelization features occur and also fine-grained sandstones and muddy siltstones are documented (Fig. 3a).

The lower interval starts with normally graded tabular beds comprising fine-grained conglomerates capped by 0.10–0.60 m thick muddy siltstones (Fig. 3b). The muddy siltstones exhibit symmetrical to slightly asymmetrical ripples with straight to sinuous and partially bifurcated crests. The succession is followed by medium-grained, massive and parallel laminated sandstones that preserve symmetrical ripples with straight crests. They are amalgamated and show tabular geometry, locally with erosive bases. Then, heterolithic deposits 3 m thick occur, consisting of cm-thick tabular beds composed of fine-grained massive sandstones alternating with laminated siltstones. Scarce casts of halite cubic crystals were found in these deposits. Above these sandstones, there are two fine-grained conglomerate beds separated by heterolithic intervals as already described. These conglomerates are poorly channelized with an orientation axis that indicates a NW-SE paleoflow direction. The top of the channels show muddy drapes with desiccation cracks.

The upper interval starts with intercalations of heterolithic deposits (1.70–2.00 m thick) and fine- to medium-grained amalgamated sandstones (1.00 to 1.50 m thick), occasionally with fine-grained conglomerates. The heterolithic intervals comprise fine-grained massive sandstones and laminated muddy siltstones with desiccation cracks and some indurated massive beds with a high content of carbonate (Fig. 3c). The amalgamated sandstones consist of tabular to lenticular beds, with mud intraclasts towards the base. Lenticular sandstone beds show tabular to tangential cross-stratification in sets of 0.30–0.80 m thick, limited by low-angle reactivation surfaces draped by muddy siltstones (Fig. 3d). Sets of trough cross-bedded sandstones also appear, although they are scarce. Some sandstones beds are topped by muddy siltstones that display desiccation cracks. One of these levels shows the preservation of invertebrate ichnogenera including vertical *Diplocraterion* Torell, 1870, tubes and horizontal winding trace fossils possibly assigned to *Helmintoidichnites* Fitch, 1850. The upper interval ends with a thick deposit (8.70 m) that consists of ripple and parallel laminated cm-thick sandstone packages, with intercalations of poorly laminated siltstones and mottled mudstones. Muddy drapes on tops of sandstones exhibit desiccation cracks (Fig. 3e) and glossy surfaces where corrugations (possible wrinkle marks) are common.

The sauropod tracks are documented in the upper interval on a flat, exposed surface of about 150 m^2 (Figs. 3f, 4). The track-bearing level is a tabular fine- to medium-grained sandstone bed covered by a thin layer of muddy siltstone that occurs intercalated between channelized deposits. Additionally, it shows symmetrical ripples in one area and desiccation cracks in another (Fig. 4b). Ripple crests are oriented SW-NE and characterized by wavelengths of 6.00–8.00 cm and heights of 1.00–1.50 cm (Fig. 4).

The lower interval is interpreted as unconfined flow deposits possibly related to ephemeral fluvial systems (e.g. Fisher et al., 2007). The fine-grained conglomerates suggest channel lags moved by bedload traction. They are capped by muddy siltstones that might have resulted from ephemeral events that episodically occurred into a fine-grained floodplain (Legarreta and Uliana, 1998). The vertical reduction in grain size and preservation of asymmetrical ripples on top indicate the progressive reduction of energy during discharges. Additionally, the muddy siltstones show desiccation cracks that indicate that these areas dried out between discharge events. The tabular massive to laminated fine-grained sandstones might have resulted from unconfined flows and occur within m-thick heterolithic deposits that are interpreted as floodplain deposits containing temporarily ponds (Abdul Aziz et al., 2003). These deposits exhibit symmetrical ripples which indicate orbital wave flows. In these deposits, the occurrence of halite cubic crystals point to saline and alkaline ground water under semi-arid to arid conditions (Hay, 1981).

The upper interval contains amalgamated sandstones that show basal and internal erosional surfaces which suggest multistorey channelized to poorly channelized flows and floodplain deposits. These channel deposits show fining-upward trends with mud intraclasts towards the base, probably as a consequence of erosion of floodplain deposits. Sandstones with planar to tangential cross-stratification are more common than trough cross-stratification and might represent channel bedforms such as 2-D and 3-D bars, respectively. In some cases, sand bodies contain lateral accretion surfaces reflecting lateral migration of channels probably related to more permanent fluvial conditions than those observed in the lower interval, dominated by low-sinuosity channels. This is consistent with the observations made by Gazzera and Spalletti (1990) for the lowermost part of the Candeleros Formation where amalgamated, low-sinuosity sandy channels dominate with absence of vegetation and pedomorphic features. The ripples and desiccation cracks on top of the amalgamated sandstones channels suggest avulsion or abandonment and complete desiccation. The fine-grained sandstones and laminated muddy siltstones of the floodplain deposits contain thin calcareous beds characterized by light coloration that suggest carbonate precipitation due to fluctuations in the chemical condition of the ground-water table with the formation of concretionary beds (Retallack, 2001). Desiccation cracks point to alternation between wet and dry periods and the periodic dewatering of the floodplains.

The sauropod trackway-bearing level is found in uppermost deposits intercalated between channels. The fact that this sandstone level with muddy siltstone draps exhibits small, symmetrical ripples and desiccation cracks points to a shallow water body with temporarily exposure, where the sauropod walked throughout it. The taphonomic sequence is discussed in the section 6.

5. Trackway description

The trackway consists of five manus-pes set, while the manus-pes set number 3 and the first manus is missing (Fig. 4). The direction of the trackway advance is 25º N, approximately parallel to the ripple crests. The tracks are preserved as concave epireliefs and most include rims.

The pes track shape is not uniform varying from rhomboidal to subcircular to subrectangular. The posterior margin of the track is subtriangular to subcircular and lacks digit impressions. In almost all cases, the posterior margin is narrower than the anterior margin. The pes imprints are longer than wide (average length and width of 98 and 82 cm, respectively) and the major axis is almost parallel to the trackway midline. The measurements are summarized in Table 1.

The best preserved manus track (track 8) presents an asymmetrical crescent shape, a concave posterior margin and a convex anterior one and exhibits an acuminate external edge (Figs. 5a, c–e). It is 60 cm in length and 67 cm in width and no digit imprints are present. This manus track has a different morphology than the others. The shape of the rest of the manus tracks is modified by the overlap of the pes tracks, giving them a symmetrical crescent shape. The major axis of the manus tracks is rotated outwards (about 30º) relative to the trackway midline.

Some rims are wider than high, as in the case of track 4 (Fig. 5b) that has a rim of up to 35 cm wide (measurement taken from the anterior margin), while in other tracks rims are higher than wide (e.g., track 8). The rims of the left tracks are more conspicuous than the ones of the right tracks, and predominantly more developed on the left side of each track. The most complete rims preserve ripples on top in perfect condition, while these are not preserved inside the tracks. All rims lack cracking.

The heteropody (H) was calculated only for the 7-8 track set because in the other cases the pes tracks overlap the manus ones (Figs. 5a, c–e). The area of track 8 (manus) and track 7 (pes) was 1769 cm² and 5729 cm², respectively, and this resulted in a medium heteropody (H = 31% ~1/3). The heteropody index (HI) for the 7-8 track set is approximately 54%. This implies that there is an overestimation of its dimension due the curved manus shape. Therefore, the heteropody index (HI) is not considered an appropriate approach to estimate the area of the manus imprints studied in this work, while the heteropody (H) is more suitable. In order to quantify and analyze the degree of manus overprinting, a ratio between the area of the only manus imprint without overprint (1769 cm²; track 8) and the average of all the manus-imprint areas with overprint (1055 cm²; tracks 4, 10 and 12) was calculated. This resulted in a relatively high percentage of manus-pes overlapping (60%).

The track pace angulation (ANG), the width of the angulation pattern (WAP), the pes trackway ratio (PTR) and the ratio between the width of the angulation pattern and the corresponding track length (WAP/PL) have only been calculated for track 9 (which involves the 7-9-11 manus-pes sets). The ANG and WAP for that track were 129º and 73 cm, respectively. Because track 5 is missing, the outer trackway width (oTW) for pes 3 and 7 was obtained drawing a straight line (*sl*) between the outermost points of tracks 1 and 9 (Fig. 2). As a consequence, the PTR of tracks 3 and 7 was estimated. The minimum PTR (track 3) is of 49.06% while the maximum PTR (track 9) is of 58.89%. The Mean PTR is of 52.54% which represents a narrow-gauge trackway (*sensu* Romano et al., 2007). The WAP/PL for track 9 is of 0.74, which also points to a narrow-gauge trackway (*sensu* Marty, 2008).

6. Substrate conditions and preservational characteristics of the tracks

The substrate type and its consistency can be inferred by the preservation characteristics of the tracks (Manning, 2004). For instance, cohesive sediments tend to bulge up into an inflated smooth rim with an unbroken surface, while more friable sediments, tend to bulge into a radially cracked displacement rim and spill sediment onto the track surface (Thulborn, 1990). The lack of cracking in the studied tracks suggests that the substrate was cohesive.

One important source of evidence to understand the substrate conditions associated with track emplacement are the rim features (e.g. size, shape, development and location). The rims of the studied tracks are larger than other rims of sauropod tracks of similar size, e.g. *Breviparopus taghbaloutensis* Dutuit and Ouazzou, 1980. Also, rims are more developed in the area with ripples than in the area with desiccation cracks, which suggests different substrate consistency (Fig. 4b). Some tracks present incomplete rims due to differential erosion and there is no significant change in track morphology along the trackway.

As was mentioned above, the sauropod trackway-bearing paleosurface shows the presence of small, slightly symmetrical ripples generated in a shallow water body in a ponded floodplain. No ripples are preserved inside the tracks, which suggests that after the tracks were produced no relevant increase in the water level occurred (e.g., Figs. 5c–e). Desiccation cracks are not present on the rim or inside the tracks, therefore their formation is previous to the generation of the tracks and possibly also of ripple formation.

As far as the authors of this work know, the ripples preserved in perfect conditions on top of the rims (e.g., Fig. 5b) are unprecedented in the track record. As a consequence of the pressure applied by the sauropod autopod, the substrate (probably well drained but still moist) behaved homogeneously during the deformation generated by the tread, suggesting that it was cohesive or stabilized in some way, otherwise ripples should have collapsed or liquefied. However, the absence of anatomical features inside the track suggests that, due to the pressure applied during the track generation, the underlying wet sediments liquefied. Every track is relatively deep and no other animal imprints of less weight were preserved. Moreover, no evidence of broken sediment layers, as a consequence of the penetration of the autopod, was observed. This implies that the studied tracks are not underprints *sensu* Marty et al. (2009). Track depth criteria alone can be insufficient to differentiate true tracks from undertracks (Sanz et al., 2016). Ripples preserved on both the track-bearing paleosurface and rims suggest that these tracks are true tracks instead of undertracks. All tracks have a clearly defined outline but no anatomical details of the trackmaker autopod were preserved. Therefore, there are no elite tracks.

7. Ichnotaxonomic discussion

Sauropod trackways have usually been differentiated into two categories depending on the distance between the pes tracks and the midline of the trackway: “wide-gauge” when the tracks are far from the midline and “narrow-gauge”, when they are located near it (Farlow

1992; Lockley et al. 1994a). These types of trackways were based on two well-known ichnotaxa: *Brontopodus birdi* Farlow et al., 1989, which has been originally named to group trackways from the Lower Cretaceous Glen Rose Formation (Texas, USA) and *Parabrontopodus mcintoshi* Lockley et al., 1994a, created to assign several specimens from the Upper Jurassic Morrison Formation (Colorado, USA), respectively.

Brontopodus is characterized by having pes tracks with outwardly directed claw-digit traces in the anterolateral part of the track and a clear lateral notch. The manus imprint are symmetrical, U-shaped and with two digit impressions oriented posteriorly with no claw marks. It has a medium heteropody (about 1:3) and is wide-gauge (Farlow et al., 1989). *Parabrontopodus* presents pes tracks longer than wide (mean length and width of 78 cm and 56 cm, respectively), three claw traces oriented laterally, and lacks a clear lateral notch. It has a pronounced heteropody (about 1:4 or 1:5), with crescent-shaped manus prints (mean length and width of 24 cm and 38 cm, respectively), without digit imprints (Lockley et al., 1994a). The Aguada de Tuco trackway has a similar heteropody to *Brontopodus*, but the manus-pes shape and gauge are clearly different. *Parabrontopodus* is narrow-gauge and presents similar manus track shape as the present trackway. Nevertheless, the latter is characterized by a less pronounced heteropody, the lack of pes-digit imprints and a greater manus-pes track size than *Parabrontopodus.*

Breviparopus from the Upper Jurassic of Morocco presents a pes tracks with four digit impressions located and oriented anteriorly and with a lateral notch (Dutuit and Ouazzouz, 1980). The manus print is symmetrical, crescent-shaped, and without digit imprints. *Breviparopus* is narrow-gauge, PTR of 50.2% calculated by Marty et al. (2010), and 51.48% and 53.54% calculated by Romano et al. (2007) based from the interpretative figures of Ishigaki (1989) and Thulborn (1990), respectively. The trackway has manus tracks located farther away from their midline than pes tracks, and these slightly overlap the manus tracks. Dutuit and Ouazzouz (1980) also mentioned a pronounced heteropody (1:3.6) for *Breviparopus*. The Aguada de Tuco trackway presents a similar heteropody and manus-pes track size, it is also narrow-gauge, but has a different position of the manus relative to the pes, and the manus is distinctly asymmetrical and lacks digit imprints.

The only two ichnotaxa of sauropod tracks recorded from the Upper Cretaceous of the Neuquén Basin are *Sauropodichnus giganteus* Calvo 1991, from the Cenomanian Candeleros Formation, and *Titanopodus mendozensis* González Riga and Calvo 2009, from the upper Campanian–lower Maastrichtian Loncoche Formation.

According to the modified diagnosis of Calvo (1999), *Sauropodichnus giganteus* comprises subtriangular pes tracks without heel and digit imprints, and a mean length and width of 80 and 60 cm, respectively. The manus track has a crescent shape with a concave posterior margin and a convex anterior one, without digit imprints and a mean length and width of 25 and 40 cm, respectively. The holotype of *Sauropodichnus giganteus* is poorly preserved (Lockley et al., 1994b). Calvo (1991, 1999) and Calvo and Mazzetta (2004) refer to this ichnotaxon as a trackway with tracks well separated from the midline. In those works, only the average measurements are described and not the individual ones of each track, and it is not indicated whether the track measurements and their figures were taken from the internal or external rim. In the present study, PTRs and mean PTR were calculated for *S. giganteus* with the available information to compare it with other ichnotaxa using the same criteria. According to the mean pes track width and oTW of Calvo and Mazzetta (2004), the resultant PTR is of 42.86%. Calculating the pes track width and oTW of each track from Calvo and Mazzetta (2004: fig. 4) and Calvo (1999: fig. 19), the mean PTR resulted in 37.88% and 36.09%, respectively. These values would indicate that *Sauropodichnus giganteus* is a medium-gauge trackway.

Titanopodus mendozensis presents manus tracks (mean length and width of 19.6 cm and 32.2 cm, respectively) without claw imprints, rotated outward (25–48º), with asymmetrical crescent shape and acuminate external edge, and subtriangular to subcircular pes tracks, longer than wide (mean length and width of 46 cm and 42.4 cm, respectively) and rotated outward. *T. mendozensis* presents a heteropody of 1:3 and is a wide-gauge trackway, with a mean PTR of 29% (González Riga and Calvo, 2009).

The Aguada de Tuco trackway presents crescent-shaped manus tracks more asymmetrical than *S. giganteus*, but similar to *T. mendozensis* in shape and in rotation angle. While the Aguada de Tuco trackway has similar heteropody to both *S. giganteus* and *T. mendozensis*, the manus-pes tracks are greater in size than any specimen of those ichnotaxa. Recently, González Riga and Tomaselli (2018) documented new examples of *T. mendozensis* with manus overprinting, something not reported for *S. giganteus* until now. Furthermore, *S. giganteus* and *T. mendozensis* are medium and wide-gauge trackways, respectively, while the trackway described in the present work is narrow gauge. Therefore, it is clearly different from *S. giganteus* and *T. mendozensis*. While walking style and substrate properties may in some cases determine variations in the sauropod trackway gauge (Castanera et al, 2012), there is no evidence that this occurs in any single trackway referred to *S. giganteus* as well as in the Aguada de Tuco trackway. No significant variation in the direction of travel or in speed (change in the stride) was registered. Consequently the differences between the gauges of *S. giganteus* and the Aguada de Tuco trackway should rather be determined by the anatomy of the animal (see section 8).

Apesteguía et al. (2010) reported one isolated manus-pes track set from the Candeleros Formation but only mentioned the heteropody without any description and no specific geographical provenance. In figure 6 of Apesteguía et al. (2010) it is observed that the uppermost layer broke when the trackmaker penetrated the tracking surface. As a result, a thin layer preserved within the tracks shows discontinuity with the aforementioned layer. Accordingly, it is interpreted that those track are underprints. Both manus and pes tracks lack claw imprints, the former has a symmetrical crescent shape, and the latter is subtriangular to subcircular in shape. The pes track does not overprint the manus track and apparently, it is wider than long. Precise measurements were not made due to the perspective of the photo. The Aguada de Tuco trackway presents manus-pes tracks larger in size (possibly twice the pes length) than the tracks reported by Apesteguía et al. (2010) and exhibit an asymmetrical manus track. The heteropody cannot be compared reliably due to the mentioned limitations.

Cenomanian sauropod tracks are scarce worldwide. Mezga and Bajraktarević (1999) described sauropod tracks of that age from the islet of Fenoliga in southern Istria, Croatia. Their manus tracks are subcircular (12–19.33 cm in length and 15.00–23.50 cm in width) while their pes tracks are bigger and circular-elliptical showing heels and four digit imprints (29.50–40.19 cm in length and 16.25–33.50 cm in width). In most cases the pes completely overprints the manus, but due to the lack of certain data in Mezga and Bajraktarević (1999), an adequate comparison of the manus-pes overlapping with the current case could not be made. Using the mean measurements available from four trackways (Mezga and Bajraktarević, 1999, Tables 1 and 4), the PTR was calculated: three are wide gauge (28.80–30.35%) and one is medium gauge (45.37%). Mezga and Bajraktarević (1999) concluded that their tracks, although smaller, are most similar to *Brontopodus*. Dalla Vecchia et al. (2001) documented several sauropod trackways from another tracksite (Karigador) in Istria, Croatia. These trackways present manus tracks with symmetrical crescent shape and no clear digital imprints are recognizable. Both manus and pes imprints present outward rotation. The mean pes track length for each trackway ranges from 32 cm (trackway KAR-S5) to 40 cm (trackways KAR-ST1 and 2). The best preserved pes track has a subtriangular to elliptical shape. These authors concluded that both trackways KAR-ST1 and KAR-ST2 clearly differ from *Brontopodus*, but they do not assign them to any ichnotaxon. They also suggested that the trackways are probably medium gauge *sensu* Meyer et al. (1994: fig. 4). The mean PTR and WAP/PL ratio calculated for track 3 to 6 of trackway KAR-ST1, measured from the inner rim (Dalla Vecchia et al., 2001: fig. 11), is about 39% and 1.18. Both values would indicate that this trackway is medium gauge as was suggested by the authors. Ibrahim et al. (2014) described two isolated crescentic tracks bearing digit imprints, from the possibly Cenomanian Kem Kem Beds of Morocco. In regard to these Cenomanian records, the Aguada de Tuco trackway presents different manus-pes shape, significant larger size and absence of digit imprints. Compared to any trackway of Istria it also presents a different gauge.

The Aguada de Tuco trackway shows certain differences with all the records mentioned. However, taking into account their preservation, an ichnotaxonomic assignment is not pursued here and the tracks remain undetermined.

8. Trackmaker characteristics and affinity

Trackway overlapping is present in both narrow and wide-gauge trackways (e.g. Dutuit and Ouazzouz, 1980; Mezga and Bajraktarević, 1999; Wright et al., 2005). Falkingham et al. (2016) concluded that the manus overprinting can be produced with any gait (e.g. pace, walk or amble), and this is the result of a particular combination of body size (Dg-a) and limb phase (LP) independently of the stride length (SL). As was mentioned previously, the Aguada de Tuco trackway presents a high percentage (60%) of manus overlapping: in average, the pes overprints more than half of the manus track. The only exception of a complete overprinting would be the first manus (track 2). Owing to the relatively short extension of the trackway, it is difficult to identify a possible turn of the trackmaker (see Torcida et al., 2015). However, the similar overprinting degree in the majority of the track suggests that no significant turn were produced.

Wide- and narrow-gauge trackways present a similar temporal distribution in the Jurassic, and while wide-gauge trackways predominate during all the Cretaceous, narrow-gauge trackways are poorly represented during the same period (Wilson and Carrano, 1999; Mannion and Upchurch, 2010; Falkingham et al., 2012). Post-Jurassic narrow-gauge trackways have only been documented in the Early Cretaceous: Moratalla (2009) and Castanera et al. (2016) described narrow-gauge sauropod trackways in the lower Aptian from the Cameros Basin (Spain). Furthermore, Santos et al. (2015) reported a narrow-gauge trackway in the Galé Formation (Albian) at Parede beach (Cascais, Portugal). Beyond the Iberian Peninsula, an alleged narrow-gauge sauropod trackway from the Cretaceous Jindong Formation (Albian) in Korea was documented by Lee and Lee (2006), whereas the narrow gauge category in the Late Cretaceous was not reported until the present contribution. The distribution of medium-gauge trackways has been poorly considered and the temporal division of sauropod gauges is not clear (Romano et al., 2007). Mannion and Upchurch (2010) registered a positive correlation of narrow-gauge trackways with coastal paleoenvironments (estuarine, deltaic, lagoonal, and carbonate platform settings), and of wide-gauge trackways with inland paleoenvironments (fluvial, lacustrine, floodplain and eolian settings). However, the narrow-gauge Aguada de Tuco trackway is not in accordance with this correlation because it is preserved in a floodplain inland paleoenvironment.

As was previously mentioned, the direction of the trackway is approximately parallel to the wave ripple-crest trend interpreted to be generated in a shallow body of water with temporary exposure within the floodplain. Physical barriers, like shoreline lakes, could condition the direction of sauropod walking (Lockley et al., 1986; Marmi et al. 2014). However, in the level bearing the Aguada de Tuco trackway no channel features were observed, and in the studied succession no significant physical barriers like large fluvial channels or lake deposits were recognized. Accordingly, the trackmaker movement was probably indirectly related to the nearby border of a pond.

Wilson and Carrano (1999) pointed out that “wide-gauge trackways were the products of wide-gauge sauropods, rather than narrow-gauge sauropods of different sizes or engaged in different behaviours”. These authors concluded that a particular gauge results from certain anatomical characteristics. The application of geometric morphometric analyses to titanosauriform stylopodial limb elements showed that humerus and femur shape were significantly different than those of other sauropodomorphs and supported the wide-gauge posture of titanosauriform (Ullmann et al., 2017). Santos et al. (2009) defined a wide-gauge sauropod trackway as *Polyonyx gomesi* from the Middle Jurassic of Portugal and suggested that was made by a eusauropod non-neosauropod, possibly a turiasaurid. They concluded that wide-gauge sauropod trackways were not exclusively made by Titanosauriformes.

Potential trackmakers for sauropod tracks of the Candeleros Formation have already been proposed: Calvo (1999) suggested that tracks assigned to *Sauropodichnus giganteus* could be produced by the basal titanosaurid *Andesaurus delgadoi*. This was concluded on the basis of: i) the shape of the manus track, which would coincide with the expected for titanosaurids, whose autopods lack phalanges; ii) the skeletal morphology of titanosaurids that suggests these were wide-gauge trackmakers (sensu Lockley et al., 1994a); and, iii) that *S*. *giganteus* and *A*. *delgadoi* were both recorded at the same stratigraphic level and only 500 m apart. Even though *Sauropodichnus giganteus* is a medium-gauge trackway, the mean PTR value is very close to the range of wide-gauge category (*sensu* Romano et al., 2007). Therefore, it is still very possible that their producer was a titanosaurid as proposed earlier by Calvo (1999). Apesteguía et al. (2010) suggested that one particular isolated manus-pes track set from the Candeleros Formation could be produced by rebbachisaurids based on the relatively high heteropody in contrast to the alleged homopodous trackways from the same geological unit attributed to titanosaurids (Calvo, 1991), and also based on the abundance of rebbachisaurid remains in the same area and unit. However, the holotype of *S. giganteus* attributed to titanosaurids presents apparent homopody as a result of its poor preservation and, according to the diagnosis amended by Calvo (1999), it is considered a heteropodous trackway. Therefore, the attribution of manus-pes track set described by Apesteguía et al. (2010) to a rebbachisaurid is not strongly supported and a titanosaurian trackmaker shoud not be discarded.

As previously mentioned, the Aguada de Tuco trackway is narrow gauge. Although quadruped narrow-gauge trackways could be attributed to ankylosaurid dinosaurs (Petti et al., 20010), even when tracks do not preserve anatomical characters, no ankylosaurid remains or any other potential quadrupedal dinosaur trackmaker other than sauropods were documented in the Candeleros Formation (Leanza et al., 2004; Pereda-Suberbiola et al., 2015). More importantly, tracks of approximately 1 m in length (as in the present trackway) or larger are exclusively attributed to sauropods (Thulborn et al., 1994; Lockley et al., 2007). Given the gauge type, a titanosauriform is disregarded as their possible trackmaker. In the Cretaceous of Argentina, sauropodomorphs non-titanosauriforms are only represented by diplodocoids (Otero and Salgado, 2015). Narrow-gauge trackways have been typically associated with diplodocoid trackmakers (e.g. Lockley et al., 1994a; Wilson and Carrano, 1999; Day et al., 2002; Wright, 2005; Moratalla, 2009; Santos et al., 2009, 2015) and in the

Upper Cretaceous of Argentina the only remains of diplodocoids that have been found are the rebbachisaurids (Otero and Salgado, 2015). In the Candeleros Formation this record includes only three taxa: *Limaysaurus tessonei*, *Rayososaurus agrioensis* and possibly *Nopcsaspondylus alarconensis* Apesteguía, 2007 (Calvo and Salgado, 1995; Apesteguía, 2007; Carballido et al., 2010). The gleno-acetabular distance and the acetabulum hip height of the rebbachisaurid *L. tessonei* were measured from the illustration of the holotype (Calvo and Salgado, 1995: fig. 17) and resulted in about 3.10 m and 2.50 m, respectively. This material is not compared herein with any track because the autopod is only known through a few disarticulated metatarsals and metacarpals. *N. alarconensis*, and especially *R. agrioensis*, present remarkably smaller dimensions than *L. tessonei* (Calvo and Salgado, 1995; Bonaparte, 1996; Apesteguía, 2007; Carballido et al., 2010). *Cathartesaura anaerobica* Gallina and Apesteguía 2005 and an indeterminate rebbachisaurid described by Haluza et al. (2012), are known from the overlying Huincul Formation (upper Cenomanian). Both specimens are composed of fragmentary remains without the hindlimbs complete; consequently, the gleno-acetabular distance and the hip height could not be estimated. Based on the available information, *C. anaerobica* is expected to be smaller in size than *L. tessonei*.

The gleno-acetabular distance (Dg-a) of the trackmaker of the Aguada de Tuco trackway was calculated for an amble gait (Dg-a = Dm-p+SL) following the procedure of Farlow et al. (1989), resulting in a Dg-a of 3.40 m. Thulborn (1990) suggested that the acetabular height for sauropods can be calculated as 5.9L, while Lockley (1986) used 4W. With these two methods, the acetabular height for the trackmaker of the material presented herein is about 5.81 m and 3.27 m, respectively. The difference between both results is practically twice the height. Many cases are known in which there is no clear correlation between bone data and the estimations from tracks, and the calculation of acetabular heights from trackways is unadvisable (García-Ortiz de Landaluce et al., 2009). Therefore, we compared the Dg-a measured from *L. tessonei* from the Dg-a obtained from the Aguada de Tuco trackway: 3.1 m versus 3.4 m, respectively. Consequently, *L. tessonei*, the biggest diplodocoid rebacchisaurid taxon from the Cenomanian Candeleros Formation is a good candidate for trackmaker of the narrow-gauge Aguada de Tuco trackway.

9. Conclusions

A new sauropod trackway from the Cenomanian Candeleros Formation, Neuquén Basin, Argentina, has been documented in the Agua de Tuco area. The Candeleros Formation comprises a multiplicity of continental paleoenvironments. Its fluvial deposits exhibit one of the richest Cenomanian ichnodiversity in the world. The Candeleros Formation records both narrow and medium-gauge categories of sauropod trackways. The new discovery is preserved in a floodplain setting with small ponds and is composed of five manus-pes track sets of a narrow-gauge trackway. The track-bearing surface shows symmetrical ripples in one area and desiccation cracks in another. Some tracks present conspicuous rims with very well-preserved symmetrical ripples on top that are unprecedented in the track record. Due to the absence of both ripples and desiccation cracks inside the tracks, these should have been generated previously to the track formation. The Aguada de Tuco trackway does not agree with the positive correlation between narrow-gauge sauropod trackways and coastal paleoenvironments previously proposed by other authors.

Whereas theropod and ornithischian dinosaur tracks are abundant in the Cenomanian rocks worldwide, sauropod tracks are relatively scarce. Cenomanian sauropod tracks are only known from Croatia, Morocco and Argentina. Taking into account the presence of rebbachisaurid diplodocoid remains in the Candeleros Formation, the classical association of narrow-gauge trackways with diplodocoids and the inferred gleno-acetabular distance, it is suggested that the studied trackway belongs to a large-sized rebbachisaurid, with *L. tessonei* as a good candidate. The Aguada de Tuco trackway is the first narrow-gauge trackway reported from the Cenomanian (and possibly for all the Upper Cretaceous) worldwide.

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FIGURE CAPTIONS

Fig. 1. a) Satellite image of the Neuquén Basin (west-central Argentina) showing the basin boundary and major structural features (modified from Naipauer et al., 2015). The Aguada de Tuco study area is indicated by a red star. Other localities of the Candeleros Formation mentioned in the text are shown with green squares: the type locality and a work of Garrido (2010) in (1), Gazzera and Spalletti (1990) in (2), Spalletti and Gazzera (1994) in (3), Sánchez and Asurmendi (2015) in (4) and Candia Halupczok et al. (2018) in (5); b) Upper Jurassic–Paleogene stratigraphic chart for the Neuquén Basin (modified from Howell et al., 2005), showing the Neuquén Group sensu Garrido (2010). The Candeleros Formation is indicated by a red arrow.

Fig. 2. Measurements and terminology used in the present work. L length and W width of P pes and M manus, SL stride length, ANG pace angulation, WAP width of the angulation pattern, oTW outer trackway width, oTW* outer trackway width estimated from slo, slo straight line between outermost points of successive pes track preserved on the same side. slo were used to estimate PTR 3 and 7, see track description for more detail.

Fig. 3. a) Schematic log for the lowermost part of the Candeleros Formation (Cenomanian) in the Aguada de Tuco area showing the lower and upper interval; b) fine-grained conglomerates (C) capped by muddy siltstones (Ms). Scale bar = 11 cm; c) heterolithic intervals dominated by fine-grained massive sandstones capped by an indurated calcitic bed. Note the laminated muddy siltstones above this interval. Rock pick = 33 cm; d) tabular to lenticular sandstone beds with planar cross-stratification limited by low-angle reactivation surfaces (arrow). Rock pick = 33 cm; e) sandstone beds draped by muddy siltstones and desiccation cracks. Pen for scale = 14 cm; f) the sauropod trackway documented on a flat surface showing symmetrical ripples and desiccation cracks. Tracks are numbered, and double arrow indicates bidirectional oscillatory flows.

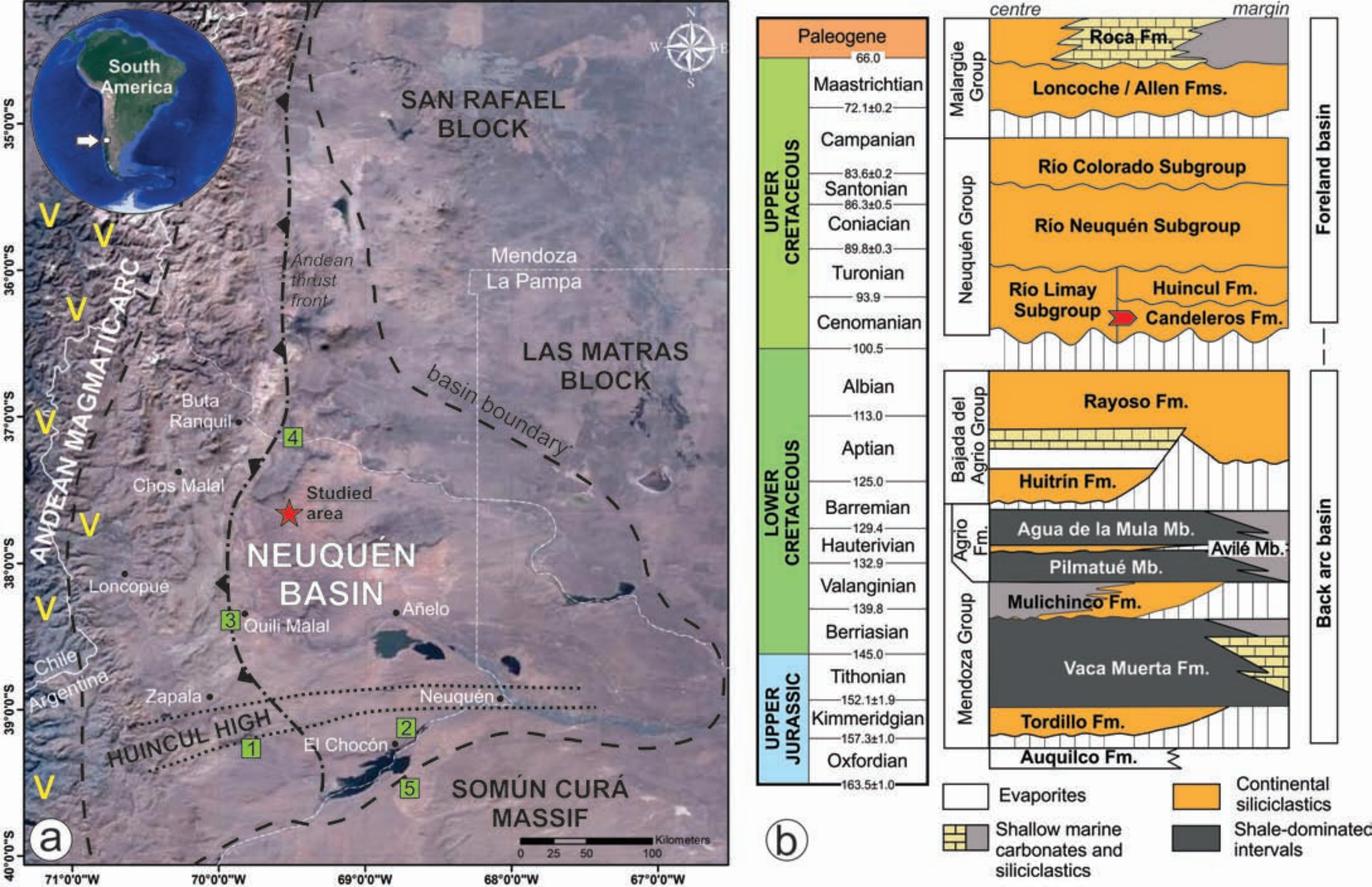
Fig. 4. The Aguada de Tuco sauropod trackway: a) field photograph of the sauropod trackway-bearing surface; b). interpretative scheme of this surface showing numbered tracks, ripples (R) and desiccation cracks (Dc). Trackway showing prominent rims (r). Scale bar = 1 m. Ripples and desiccation cracks not to scale. Double arrow indicates bidirectional oscillatory flows.

Fig. 5. a) The latest manus-pes sets of the Aguada de Tuco trackway including the only set, tracks 7 and 8, without overprinting. Note that ripples are preserved only on the left side of the tracks. Double arrow indicates bidirectional oscillatory flows; b) manus track number 4

showing conspicuous rims with very well-preserved symmetrical ripples on the top. Scale card = 11.5 cm long. The right photos display the best preserved manus-pes set 7 and 8 aforementioned: c) Picture in plane view; d) false-colour depth map of the photogrammetric 3D model, and e) contour lines map with 0.5 cm of equidistance. Scale bar = 20 cm.

Table 1. Measurements of Aguada de Tuco sauropod trackway. RP right pes, RM right manus, LP left pes, LM left manus, SL stride length, ANG pace angulation, WAP width of the angulation pattern, PTR pes trackway ratio. *the heteropody using area (H) and the heteropody index (HI) are referenced only for the pes that did not overimprint the manus.

Track	Width (cm)	Length (cm)	Area imprint (cm²)	H (%)	HI (%)	SL (cm)	ANG (degrees)	WAP (cm)	PTR (%)
1 RP	66	94	4506	-	-	-	-	-	-
3 LP	80	100	5816	12.93	27.75	293	-	-	49.06
4 LM	74	30	752	-	-	305	-	-	-
7 LP	74	100	5729	30.88*****	54.32*****	312	-	-	49.68
8 LM	67	60	1769	-	-	285	-	-	-
9 RP	106	98	7776	17.28	22.91	-	128.84	73	58.89
10 RM	70	34	1344	-	-	-	-	-	-
11 LP	83	100	7398	16.95	11.42	-	-	-	-
12 LM	79	12	1254	-	-	-	-	-	-
Average									
manus	72.5	34	1280	19.51	29.10	295			
pes	81.8	98.4	6245	~ 1/5	~ 1/3	302.5	128.84	73	52.54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SAN RAFAEL BLOCK
LAS MATRAS BLOCK
Mendoza
La Pampa
Andean thrust front
basin boundary
ANDEAN MAGMATIC ARC
Buta Ranquil
Chos Malal
Studied area
NEUQUÉN BASIN
Loncopue
Añelo
Quili Malal
Chile
Argentina
Zapala
Neuquén
HUINCUL HIGH
El Chocón
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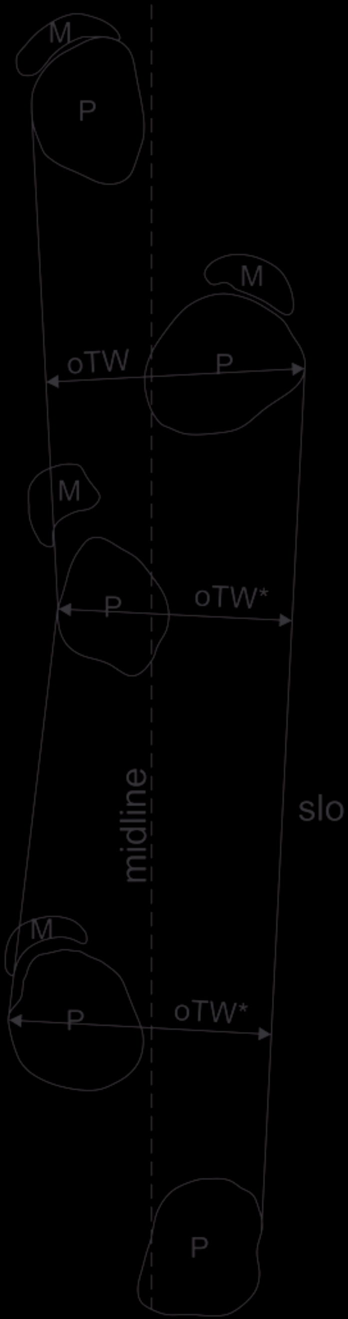
40°0'0"S
71°0'0"W
70°0'0"W
69°0'0"W
68°0'0"W
67°0'0"W
a
b
Paleogene
66.0
UPPER CRETACEOUS
Maastrichtian
72.1±0.2
Campanian
83.6±0.2
Santonian
86.3±0.5
Coniacian
89.8±0.3
Turonian
93.9
Cenomanian
100.5
LOWER CRETACEOUS
Albian
113.0
Aptian
125.0
Barremian
129.4
Hauterivian
132.9
Valanginian
139.8
Berriasian
145.0
UPPER JURASSIC
Tithonian
152.1±1.9
Kimmeridgian
157.3±1.0
Oxfordian
163.5±1.0
centre
margin
Malargüe Group
Roca Fm.
Loncoche / Allen Fms.
Neuquén Group
Río Colorado Subgroup
Río Neuquén Subgroup
Río Limay Subgroup
Huincul Fm.
Candeleros Fm.
Foreland basin
Bajada del Agrio Group
Rayoso Fm.
Huitrín Fm.
Agrio Fm.
Agua de la Mula Mb.
Avilé Mb.
Pilmatué Mb.
Mendoza Group
Mulichinco Fm.
Vaca Muerta Fm.
Tordillo Fm.
Auquilco Fm.
Back arc basin
Evaporites
Continental siliciclastics
Shallow marine carbonates and siliciclastics
Shale-dominated intervals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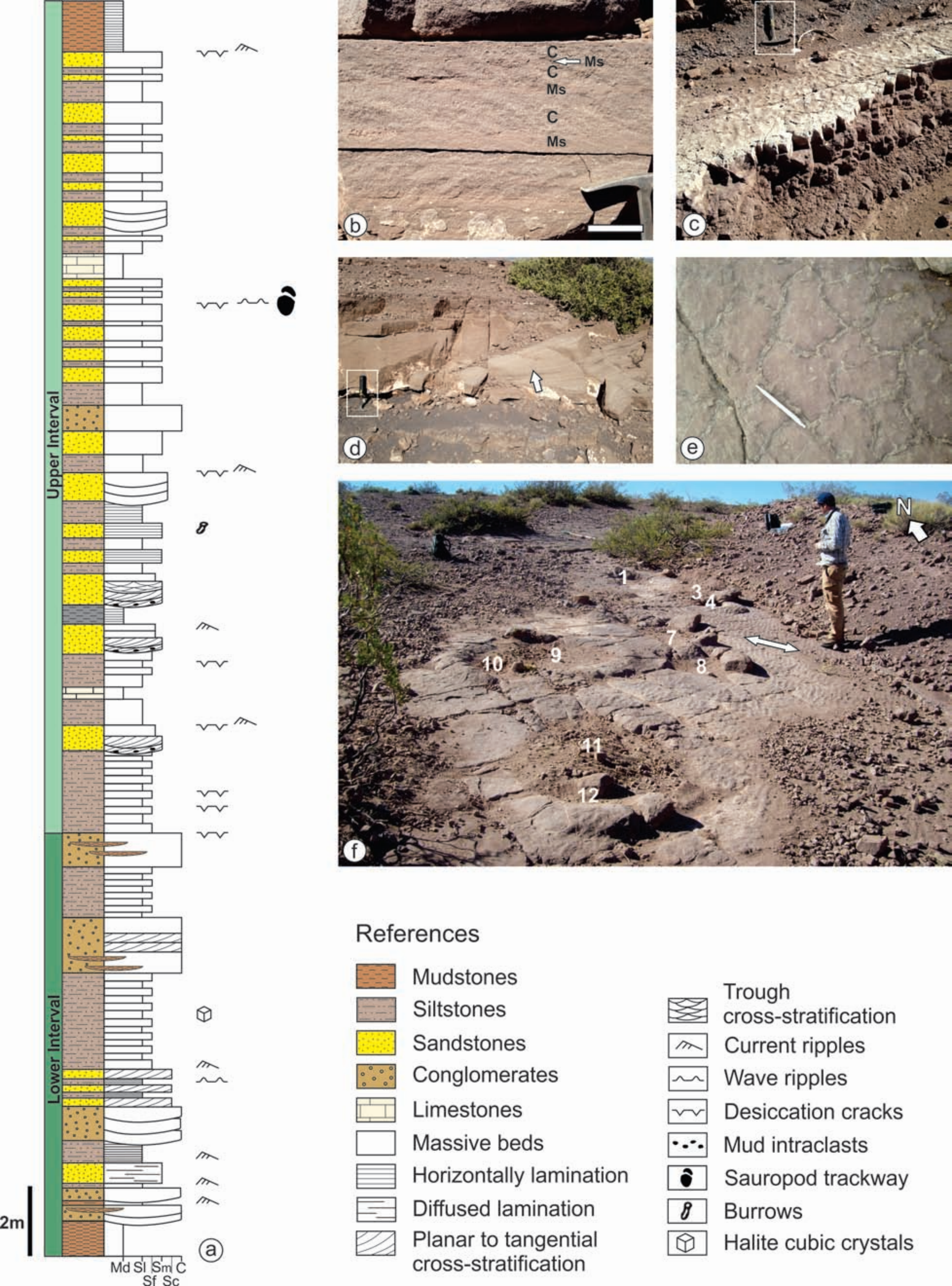
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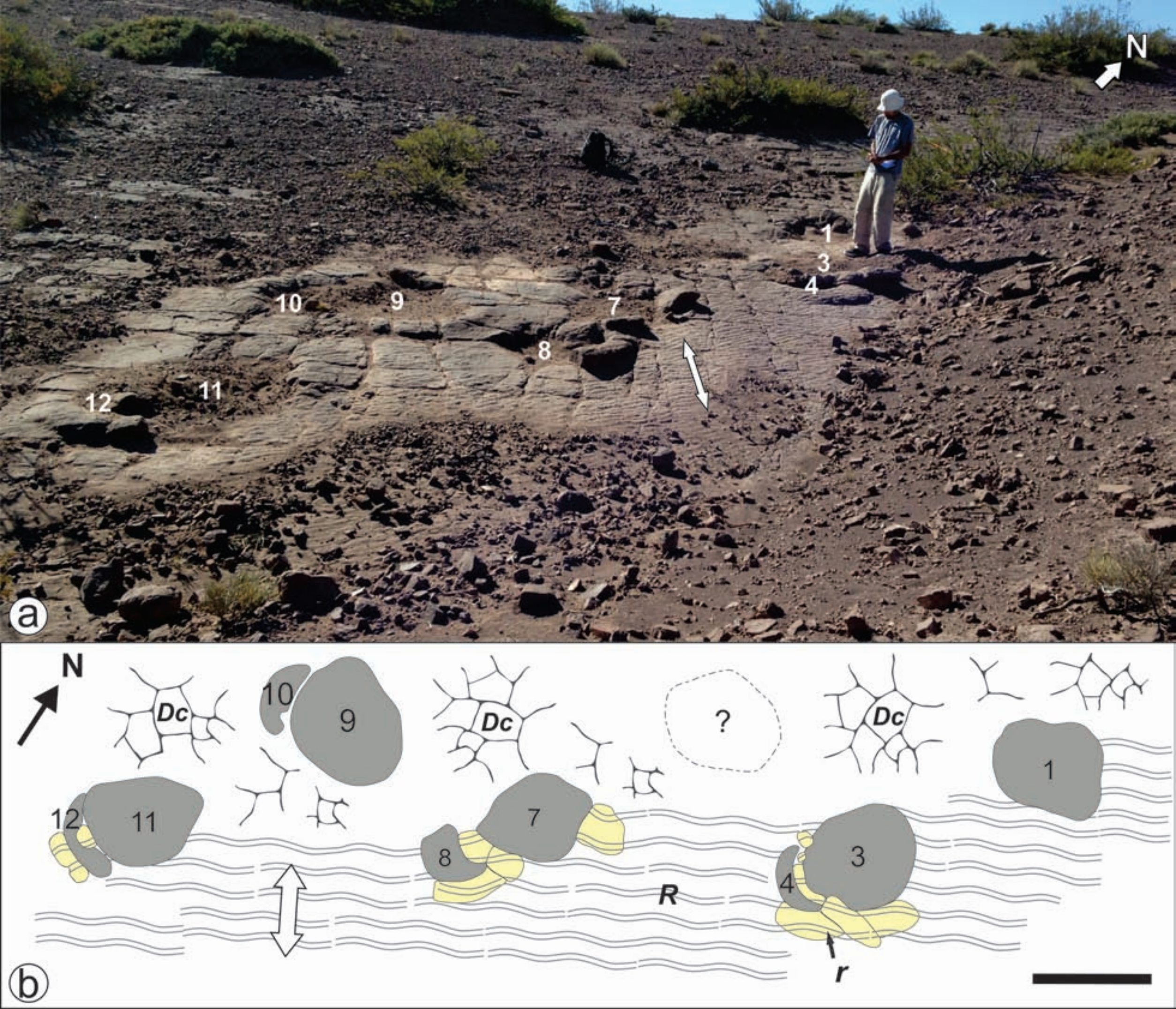
References
Mudstones
Siltstones
Sandstones
Conglomerates
Limestones
Massive beds
Horizontally lamination
Diffused lamination
Planar to tangential cross-stratification
Trough cross-stratification
Current ripples
Wave ripples
Desiccation cracks
Mud intraclasts
Sauropod trackway
Burrows
Halite cubic crystals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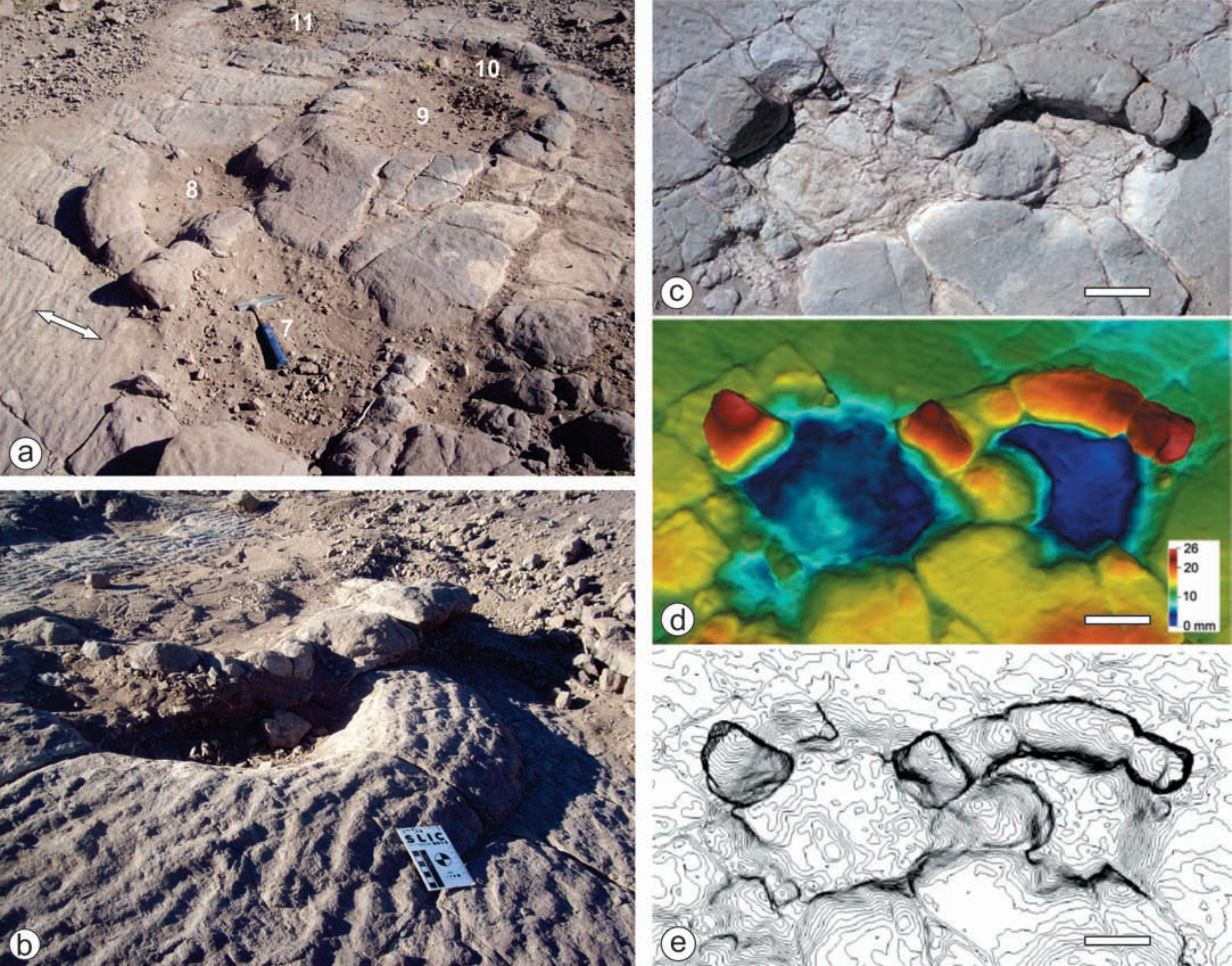
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Highlights

- First record of a narrow-gauge sauropod trackway from the Cenomanian worldwide
- Large rims with well-preserved ripples on top are documented for the first time
- A taphonomic sequence between dessication cracks, ripples and tracks is recognized
- A large-sized rebbachisaurid diplodocoid trackmaker is proposed