Jarrate Lbel: New Upper Cretaceous continental site in Morocco. A probable ornitischian non-onithopod trackway and three amble gait titanosauriform trackways

Jarrate lbel: Nuevo yacimiento continental del Cretácico Superior Marroquí. Un probable rastro ornitisquio no ornitópodo y tres rastrilladas titanosauriformes de andar amblar

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ABSTRACT

In this paper a new Upper Cretaceous site with sauropod footprints is described. The outcrop, found in Chott Tigri, in the meridional area of the High Plateau of Morocco, between the Saharan Atlas and the Middle Atlas, is separate from other known sites with dinosaur footprints. We have found: three trackways of titanosauriform features and variable gauge, and one trackway of an unknown dinosaur that we attribute to an ornithischian quadruped, but not an ornithopod. In this paper we have implemented calculations based on trackway analysis to deduce the glenoacetabular distance distance and the type of gait. In the three sauropod trackways the data are consistent with amble gait.

Key-words: *Footprints, Sauropods, Amble gait, Upper Cretaceous, Morocco.*

RESUMEN

Se describe un nuevo yacimiento con icnitas saurópodas del Cretácico Superior encontrado en Chott Tigri, en la zona de la Meseta Meridional Marroquí, entre el Atlas Sahariano y el Atlas Medio, separada del resto de yacimientos marroquies. En conjunto hay tres rastrilladas titanosauriformes de ancho de via variable, y otra de un dinosaurio desconocido que atribuimos a un ornitisquio cuadrúpedo no ornitópodo. En este trabajo se han aplicado cálculos basados en el análisis de las rastrilladas para deducir la distancia glenoacetabular y el tipo de marcha; en las tres rastrilladas saurópodas son congruentes con marcha amblar.

Palabras clave: *Icnitas, Saurópodos, Andar Amblar, Cretácico Superior, Marruecos (5 palabras máximo)..*

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Introducction

In Morocco there are many sites with sauropod footprints from the Carixian to Upper Cretaceous (Cenomanian-Turonian). The most abundant are found in carbonate facies (Lower and Middle Jurassic) and clastic facies (Upper Jurassic). In the Lower Cretaceous there is an outcrop (Talmest) and in the Upper Cretaceous another (Kem Kem). The age of the site by the Agadir-Marrakesh road is uncertain.

In this work a new site with three sauropod trackways and one of an unknown trackmaker, whose age is Upper Cretaceous, are studied. The name of the site is Jarrate Lbel (JLB). The region, in which an extensive layer with abundant bone fossils has also been found, is conducive to more discoveries. The

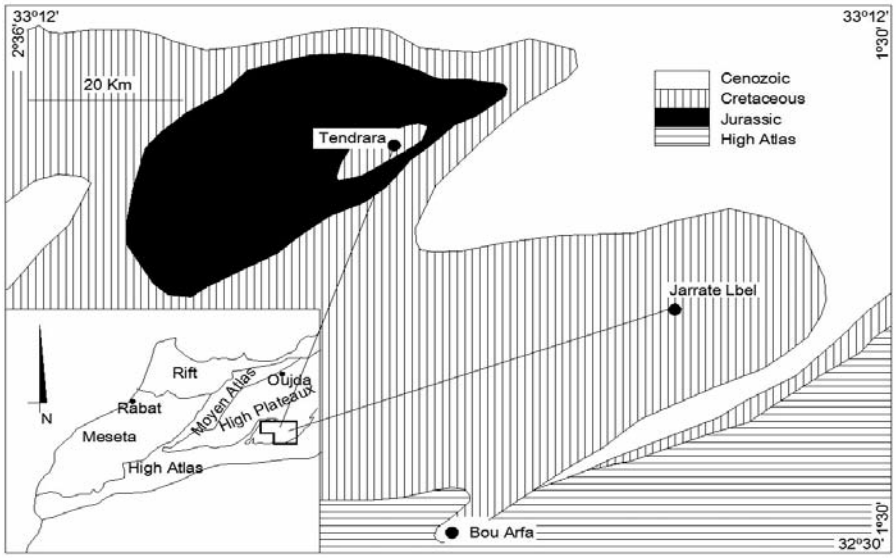

Fig. 1.- Location of Jarrate Lbel site (modified from Hadoumi et al. 2015).

Fig. 1.- Localización del yacimiento Jarrate Lbel (Modificado de Hadoumi* et al.*, 2015).

Fig. 2- Partial view of 1JLB1, 1JLB2, and 1JLB3 trackways.

Fig. 2.- Imagen parcial de las rastrilladas 1JLB1, 1JLB2 y 1JLB3.

new sauropod trackways range between the narrow and intermediate gauge and have the manus prints very close to the midline.

Due to the correlation between possible measurements of the hind limb length and of the glenoacetabular distance, it follows that the sauropod gait was ambling.

Material and method

The site (Figs.1, 2 and 3) is located to the northeast of Morocco in Chott Tigri (L'Oriental region; "Haut Plateaux Marrocaines"), about 50 km southeast of Tendrara (Fig. 1). The footprints are on a layer of medium to fine grain red sandstone whose orientation is N120E and dip 5NE. Geographic coordinates taken on site are 32°46'30 "N, 1°42'57" W and the UTM location obtained from Google-earth 30S 620252E 3627088N

Sandstone is included in the "Formation des grès et conglomérats du Chott Tigri", of Upper Cretaceous post Turonian age (Haddoumi *et al*., 2015). This Formation is divided into two members, of which the lower (Turonian-Santonian) is marine, and the upper (Santonian-Maastrichtian) is continental. The site is in the continental member, but not in its top, so probably its age can be placed in the Santonian-Campanian range.

The nomenclature (Table I) adopted is similar to the rest of our works. 1JLB is the name of the site. 1JLB2.32m is the manus print of ichnite set number 32 of trackway 2 of the first Jarrate Lbel tracksite.

The classification of the sauropod ichnites is done considering the morphological classification of Wright (2005) to which we add the heteropody value of Lockley *et al* (1994). Trackway patterns are classified according to Farlow (1992) gauge with the remarks of Lockley *et al*. (1994), Marty *et al*. (2010) and Santos *et al*. (2009).

The footpint and trackway measurements and their relationships are taken from various authors (cf, Leonardi, 1979; Pérez-Lorente, 2001, 2015). Determinations of acetabulum height are made according to the formulas proposed by Alexander (1976), h_1; Thulborn (1990), h_2; Lockley *et al*. (1986), h_3; Ishigaki (1988), h_4; and Gonzalez-Riga (2011), h_5, and glenoacetabular distance for the three types of quadruped gait as Demathieu schemes (1970, 1979): amble, evolved alternating and primitive alternating: ga_1, ga_2, ga_3.

The speed calculation is made according to the formulas proposed by Alexander (1976) and Demathieu (1986), v_1 and v_2 respectively. In 1JLB4 the running formula from Thulborn (1990) is also used.

Ichnology

In 1JLB (Fig. 3) there are currently 196 dinosaur footprints that are associated in four quadrupedal trackways (Table I). Three (1JLB1, 1JLB2, 1JLB3) are made by a sauropod and one (1JLB4) by an unknown author. The number of footprints and the length of trackways is expandable by excavation and cleaning of the outcrop. All tracks are hollow (sensu Allen, 1997) or negative epireliefs, many of which have mud extrusion rims surrounding them totally or partially

1JLB1, 1JLB2, 1JLB3

The pes prints are not large enough to be sauropod. 1JLB1 has the largest (lp = 42 cm) and 1JLB3 the smallest (l = 32 cm); they are almost equidimensional ($[l_p-a_p] / a_p \approx 0 \setminus 0.3 \setminus -0.2$). They have no digital pad marks and only in some of the1JLB1 the first 4 left pes prints seem to have nail marks, although these indentations may be due to erosion provided by the jointing of the site that has similar orientation.

In 1JLB1 the inside of the pes prints is tangent or is slightly separated from the midline ($Ar_p/a_p = 0.55$) indicating a wide gauge trackway in the Farlow (1992) sense, and intermediate in the Marty *et al*. (2010). In 1JLB2 the inside of the pes prints is slightly separated from the midline ($Ar_p/a_p \approx 0.8$) indicating that it is for Marty *et al*. (2010) widegauge. Unlike the former, the path in this case is sigmoid all the way and we do not know how this influences the possible variation of gauge width. Finally in 1JLB3 ($Ar_p/a_p \approx 0.6$) a part is wide gauge and the other narrow gauge; the inside of the pes prints is separated from the midline, although 1JLB3.14p treads and JLB3.8p, and 1JLB3.12p is tangent. It would be an intermediate gauge, or a trackway ranging between intermediate and wide gauge, i.e., a value between the two above. According to Marty *et al*. (2010) the value of the WAP / PL ratio (approximately equivalent to 2[Ar/a]) ranges from 1 to 1.2 for intermediate gauge.

The manus prints are not kidney shaped but circular. Neverthless a small section of the back is flat or concave. The manus prints are relatively large compared to those of the pes

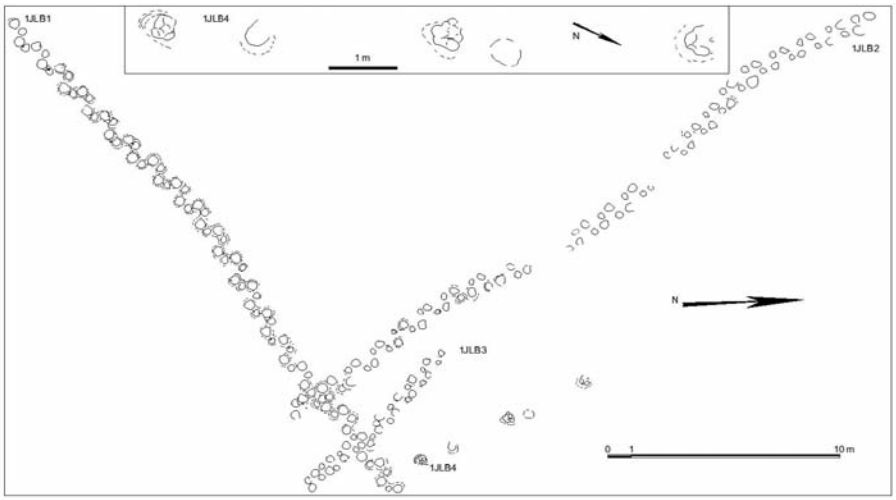

Fig. 3.- A) Jarrate Lbel trackways. B, 1JLB4 enlarged drawing.

Fig. 3.- A) rastrilladas de Jarrate Lbel. B, ampliación de 1JBl4..

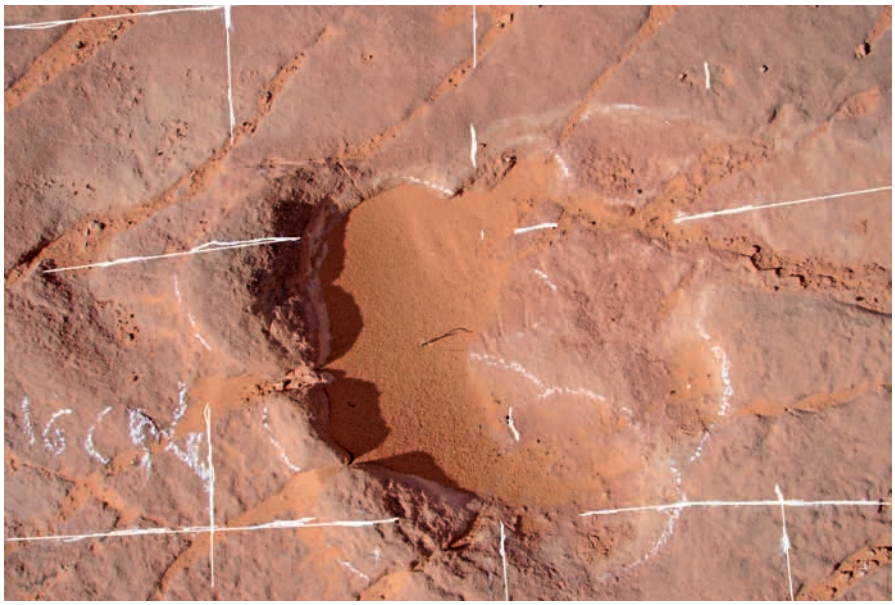

Fig. 4- 1JLB4.2p. Crayon line separation, 30 cm.

Fig. 4.- 1JLB4.2p. Las lineas de tiza están separadas 30 cm.

prints ($S_p/S_m \approx 2$). They are therefore of evolved sauropod morphology (Wright, 2005). Only in the first trackway, are some of these ichnites deformed by the pressure of the mud from pes extrusion rims.

Trackway width ($Lr_p > Lr_m$) of pes prints is greater than the manus prints of the three trackways, but the trackway deviation is greater ($Ar_p > Ar_m$) in the first two and equal in 1JLB3. Such a small difference in trackway deviation is consistent with the small difference of pace lengths and pace angles of pes and manus prints. Only in 1JLB2 is the difference in pace angle greater probably due to the sinuosity of the trackway. These measurements are not consistent with the *Brontopodus* or with *Breviparopus* (Farlow, 1992) ichnotypes

We applied the Casanovas *et al*. (1997) approach to calculate the correlation between glenoacetabular distance and dinosaur gait (Table I). The result is that the correspondence of the height of the limb with the glenoacetabular distance ($h5\backslash ga_1$) is of 191\190 cm for 1JLB1, 178\181 cm for 1JLB2 and 147\145 cm in 1JLB3, i.e. for ambling gait.

1JLB4

We associate the remaining footprints with a trackway. There are five different tracks (three [pes?] and two [manus?]) which alternate. We assume that the trackmaker is going N335E because the odd tracks (first, third and fifth, or 1, 3, 5) are more open in that regard.

Only the odd tracks (we assume of pes) have pad marks inside. In 1JLB2p two are positioned the same as digital pads. Also the odd prints have much larger mud extrusion rims, more developed at the rear of the prints. 1JLB4.2m has no extrusion features.

The pace length between the even prints (2-4) and odd prints (1-3-5) is similar (P = 390 cm), and the distance 2-3, 4-5 (110 cm) is much less than 1-2, 3-4 (280 cm). There are therefore two pairs, 1JLB1pm and 1JLB2pm (Fig. 3), evenly arranged. The front part of 1JLB3p is covered.

The trackway is very narrow ($Ar_p \approx 0$) and has a very high pace angle ($Ap_p = 180$).

The steps and stride are so great that the speed deduced is very high. z/h = 4.6 is possibly one of the largest known relationships. Viera and Torres (1995) find the same value for a theropod dinosaur which suggests that the hip height is 128 cm and the speed of 37.4 km / h.

In 1JLB4 the speed varies.from 47 km/h (Alexander, 1976) to 17 km/h (Demathieu, 1986) and to 13.6 km/h (running, Thulborn, 1990). Footprints are missing in 1JLB4 to endorse or not the running gait or other animal behavior (cf. Pérez-Lorente, 2015).

We do not know in the ichnological record of any footprint with the same characters of this trackway or morphological features similar to what we suppose pes prints (with digital pads) and manus prints (rounded).

Discussion

The placement of the foot marks of the three sauropod trackways has intermediate characters (Santos *et al*., 2009) between *Polionyx gomesi* Santos *et al*. 2009 and *Breviparopus taghbaloutensis* Dutuit and Ouazzou 1980). 1JLB1 has the lowest value of relative trackway deviation (Ar/a) and 1JLB2 the highest, which coincides with the variation of sinuosity, but not with the length of the prints or the speed variation (1JLB1> 1JLB2> 1JLB3).

Manus prints are closer to the marks of the rear pes prints than to the front pes prints, which is normal in sauropod trackways. However, they are closer to the midline than the pes which is rare in narrow gauge trackways. Given the shape of manus prints, the heteropody value, the relative position of the manus prints relative to the pes and the Upper Cretaceous age of the site, we associate the ichnites with titanosauriform trackmakers.

There are no decisive criteria of herd behavior as parallel trackways, or chaotic clusters. However, the study surface is small and we cannot make any assessment.

According to the model used in this work, it follows that the way of walking of this dinosaur was amble gait, a gait also deduced from other sites (Casanovas *et al*., 1997; Mezga *et al*., 2007; Pérez-Lorente, 2015). This is not the case in most other publications, assuming evolved alternating walking as described by Demathieu (1970, 1979).

1JLB4 ichnotaxon determination is made by removal and not by identifying their own characters. Pes prints probably have several relatively large digit and sole pad prints, no marks of acuminate or separate digits. These qualities allow us to eliminate sauropod and theropod dinosaurs as the trackmakers. These prints are not specific to ornithopods because the possible manus prints are too large and the rear end of the pes is inconsistent with a simple or a bilobed back pad.

So far the number of ornithischian non-ornithopod footprints is small, and the variability of the ichnites of the group increases as more sites are found. Similarly, the age of the site eliminates more primitive dinosaurs. With the data available for now we only assume the possibility that the author was an ornithischian non-ornithopod dinosaur. As the site is to expand, the number of prints and determination required may increase.

Conclusions

A new tracksite from the Upper Cretaceous of Morocco is described. with three

Trackway	1JLB1	1JLB2	1JLB3	1JLB4	
$l_p\backslash l_m$	42\29	40\24	32\21	42\46?	1
$a_p\backslash a_m$	40\32	31\27	32\25	46\37?	2
$Ar_p\backslash Ar_m$	22\21	25\22	19\19	0	3
$Lr_p\backslash Lr_m$	88\74	86\70	70\62		4
$P_p\backslash P_m$	84\83	83\80	65\64	390\¿?	5
$z_p\backslash z_m$	142\143	132\131	103\95	780\¿?	6
p m distance	48	40	43	110	
$Ap_p\backslash Ap_m$	116\118	106\111	105\106	180	7
$S_p\backslash S_m$	1360\753	991\550	825\448		8
$h_1\backslash h_2\backslash h_3\backslash h_4\backslash h_5$	167\162\150\229\191	160\126\144\220\178	129\119\116\176\147	168\\\	9
z_p/h	0,7	0,7	0,7	4,6	10
$v_1\backslash v_2$	2,4\3,3	2,3\2,8	1,9\2,4	13,6-47\16,9	11
$(l_p-a_p)/a_p\backslash (l_m-a_m)/a_m$	0,03\-0,10	0,30\-0,12	-0,17\-0,13	-0,09	12
$Ar_p/a_p\backslash Ar_m/a_m$	0,55\0,81	0,80\0,29	0.59\0,88	0	13
$z_p/l_p\backslash z_m/l_m$	3,4\4,53	3,4\5,74	3,1\4,9	19	14
$ga_1\backslash ga_2\backslash ga_3$	190\155\119	181\148\115	145\119\94		15

1, footprint length (l); 2, footprint width (a); 3, trackway deviation (Ar); 4, trackway width (Lr); 5, pace length (p); 6, stride length (z);7, pace angle (Ap); 8, heteropody (S = area); 9, hip or acetabular height (h); 10, relative stride (z/h); 11 speed (v); 12, relative footprint [(l-a)/a]; 13, relative trackway deviation (Ar/a); 14, relative cursorial character (z/l); 15, glenoacetabular distance (ga), p and m subscrits refer to pes and manus respectively.

Table I.- Numerical data from tracks and trackways.

Tabla I.- Datos numéricos de las huellas y rastrilladas.

sauropod trackways and another from an unknown dinosaur in an area in which no palaeoichnological sites had been discovered.

The sauropod footprints are classified as titanosauriforms due to the heteropody and the shape of the manus print. Their trackways are of intermediate gauge, and are consistent with amble gait, already cited for these animals in outcrops of Spain and Croatia.

The environment is continental detrital bright red, which means that in Morocco there are also trackways with wide, intermediate and narrow gauge in this type of environment

We found a type of ichnite so far unknown, assigning it to an ornithischian non orhithopod, waiting for definitive confirmation after the excavation of the site provides new footprints. If the attribution is checked, it would be a trackway of a quadruped ornithischian dinosaur on the run.

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