

New sinusoidal and complex trackways of *Boutakioutichnium atlasicus* from the Upper Jurassic of Iouaridène (Morocco)

Rastrilladas sinusoides y complejas nuevas de *Boutakioutichnium atlasicus* del Jurásico Superior de Iouaridène (Marruecos)

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ABSTRACT

In the syncline of Iouaridène there are extensive dinosaur tracksites containing long trackways. These trackways show the variability of the sequences of footprints and their inferences regarding the identification of trackmakers, the variability of ichnites printed by the same trackmaker and the sequences of long-short paces in relation to the possible lameness, laterality or the sinuosity of the direction along the path. This paper confirms the enormous variability of forms and the possibility that there are also other causes that determine the sequences of long-short steps within the same trackway.

Key-words: Dinosaur footprints, Oxfordian-Kimmeridgian, High Central Atlas, trackway analysis.

RESUMEN

En el sinclinal de Iouaridène hay yacimientos extensos que contienen rastrilladas largas. Estas rastrilladas muestran la variabilidad de las secuencias de pisadas con sus consecuencias relativas a la identificación de los icnopoyetas, a la amplitud de formas impresas por el mismo autor y a las secuencias de paso largo-corto en relación con la posible cojera o lateralidad o con las variaciones de rumbo a lo largo de la trayectoria. En este trabajo se confirma la enorme variabilidad de formas y la posibilidad de que no solo sean estas las causas que determinen las secuencias de pasos largos-cortos dentro de las mismas rastrilladas.

Palabras clave: Huellas de dinosaurio, Oxfordiense-Kimmeridgiense, Alto Atlas Central, análisis de rastrilladas.

Geogaceta, 64 (2018), 79-82
ISSN (versión impresa): 0213-683X
ISSN (Internet): 2173-6545

Recepción: 22 de enero de 2018
Revisión: 23 de marzo de 2018
Aceptación: 25 de abril de 2018

Introduction

The Iouaridène dinosaur ichnosites have produced from the year 1937 up to now abundant scientific publications (e.g., Boutakiout *et al.*, 2008; Nouri *et al.*, 2011). In this work, we present two sites, previously known, which had not been studied. We describe the presence and characteristics of *Boutakioutichnium*, an ichnotaxon described in several points of the zone (Nouri, 2007; Nouri *et al.*, 2011), and some ichnological aspects related to their trackways. In Iouaridène there are 43 known paleoichnological sites, but only 16 of them are studied until now. In Iouaridène two ichnotaxa have been described for the first time: *Breviparopus taghbaloutensis* (Dutuit and

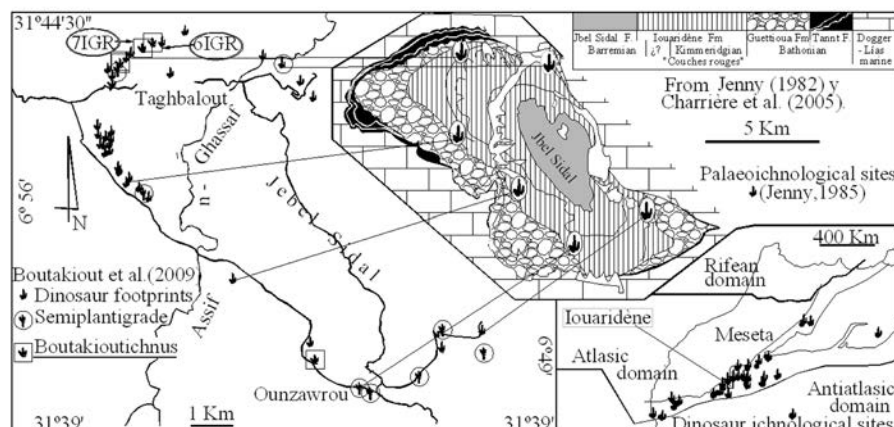


Fig. 1.- Geographical and geological location of 6IGR and 7IGR sites in the Iouaridène syncline and in Moroccan dinosaur footprint sites

Fig. 1.-Localización geográfica y geológica de los yacimientos 6IGR y 7IGR en el contexto de los yacimientos de huellas de dinosaurio de Marruecos y del sinclinal de Iouaridène.

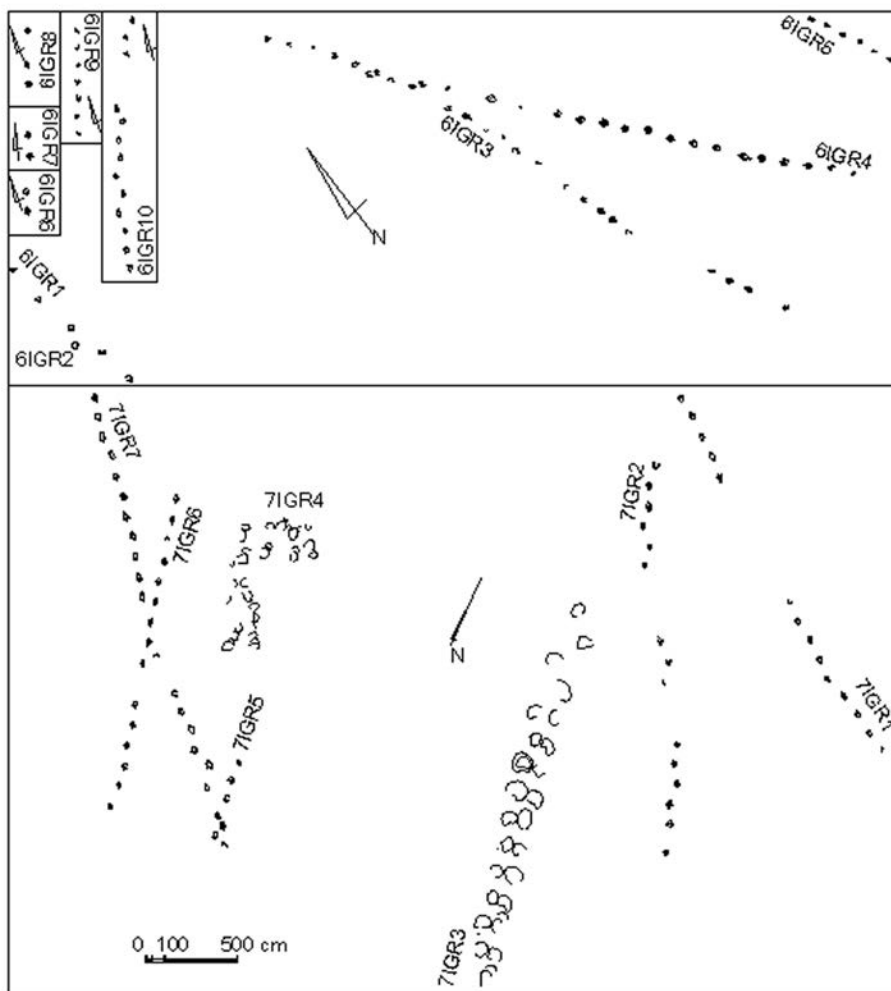


Fig. 2.- Distribution and schemes of 6IGR (top), and 7IGR (below) sites. Same scale.

Fig. 2.- Distribución y esquemas de las rastrilladas de 6IGR (arriba) y 7IGR (abajo). Misma escala.

Ouzzou; 1980), and *Boutakioutichnium atlasicus* Nouri *et al.*, 2011.

Based on Nouri (2007) and two research campaigns (Boutakiout *et al.*, 2008, 2009), this paper should be considered as an additional partial result of the palaeontological research in the Iouaridène syncline, which will enable us for the preparation of a synthesis of the set of sites of the syncline.

Geographical and geological setting

The Iouaridène syncline (Fig. 1) is located in the High Central Atlas, east of the town of Demnat, in the province of Azilal (Morocco). The UTM coordinates of the sites are: 6IGR, 29R 699470/3513100; and 7IGR, 29R 699280/3513040. The

study surface in each of the sites extends over several layers of silts with desiccation cracks of the Iouaridène Formation, of Oxfordian-Kimmeridgian age (Haddoumi *et al.*, 2010) and included in the "couches rouges" of the old geologists.

Materials and methods

For the collection of data, the sites are chalked with an orthogonal 30x30 cm network. The outline of each footprint is also marked with chalk and the structures related to them are indicated. All traces referenced with the previous network are photographed. The images and data obtained are finally treated with Adobe Photoshop and AutoCAD.

The symbols, terminology, and footprints measurements are the ones usually employed by our research team, based on classical authors (*cf.*, Pérez-Lorente, 2015). The descriptive terms defined by Allen (1997), Pérez-Lorente (2001) and Gatesy (2003) have been added. Several more authors have proposed new terms, all described in Pérez-Lorente (2015).

Ichnology

199 footprints have been counted in the two sites (6IGR and 7IGR), but only the theropod ichnites (140) have been studied in this paper. 6IGR also contains an unidentified isolated footprint (6IGR2). There are 58 additional sauropod footprints in 7IGR, 25 of which define a trackway studied by Castanera *et al.* (2010) (Fig. 2). The rest of the sauropod footprints (33) are in a group defined by 7IGR4. The theropod ichnites are distributed in 12 trackways (Fig. 3) and two pairs of footprints.

The outline of the footprints is not regular in any of the trackways (Fig. 4) but some determinative characters are identified in them (Romero-Molina *et al.*, 2003). They are large ichnites (length <30 cm, Thulborn, 1990) with relatively strong, elongated and separated, terminally acuminate digits. In some ichnites several pads are distinguished in each digit and another salient pad, in the heel. The footprints are narrow and asymmetrical: the heel is the extension of digit IV, and digit II is shorter and more parallel to digit III ($II \wedge III < III \wedge IV$, see Table I). The outline of the footprints usually draws a posterior recess in the proximal pad of digit II (Fig. 4).

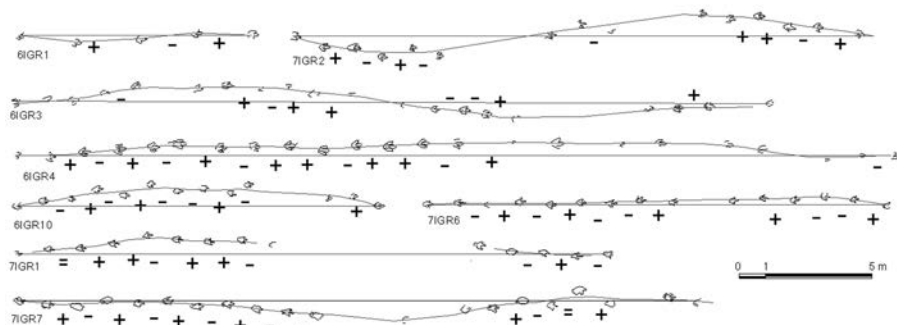


Fig. 3.- Sigmoidal 6IGR and 7IGR dinosaur trackways and variability in pace length (difference between successive pace length values: + [Pn < Pn+1] and - [Pn > Pn+1])

Fig. 3.- Trayectoria sinusoide de las rastrilladas de 6IGR y 7IGR y variabilidad del paso (diferencia de longitud entre pasos sucesivos: + [Pn < Pn+1] y - [Pn > Pn+1]).

The height of the acetabulum deduced from the footprint length ranges between 160 and 215 cm (Table I).

Almost all footprints are triadactyl, but in several trackways of 7IGR there are intercalated with them other very peculiar tetradactyl footprints characterized by the position of the hallux: large and placed perpendicularly to the axis of the foot (7IGR1.15, 7IGR6.4, 7IGR6.16, 7IGT7. 4, 7IGR7.6, 7IGR7.7, 7IGR7.8, 7IGR7.10, 7IGR7.11, 7IGR7.18, 7IGR7.19, 7IGR7.24, 7IGR7.25). Digit I (hallux) is relatively long and isolated. The proximal part of this digit is located close to the proximal part of the digit IV.

All the trackways are very narrow (Ar/a between 0.1 and 0.4), the footprints are above the midline except 6IGR5, 6IGR10, and 7IGR7, and they all have a sinusoid trajectory, except 6IGR5. Dinosaurs walk (between 3.9 and 6.3 km/h, slow to moderate), except in 6IGR1 where the value of 2.3 of the relative stride (z/h) involves trotting (Thulborn, 1990). The mean velocity of displacement in this case is 12.7 km/h. From the trackways it is also deduced that these dinosaurs had the extremities from normal to very thin (z/l of the footprint between 5 and 11).

As in other sites (Pérez-Lorente, 2003; Masrour *et al.*, 2017), it is verified here that the path in long trackways is sinuous (Fig. 2). The largest wave amplitude of the sinuosity is recorded in 7IGR2 in which the amplitude is 146 cm. This trackway has no abnormal values from the rest of

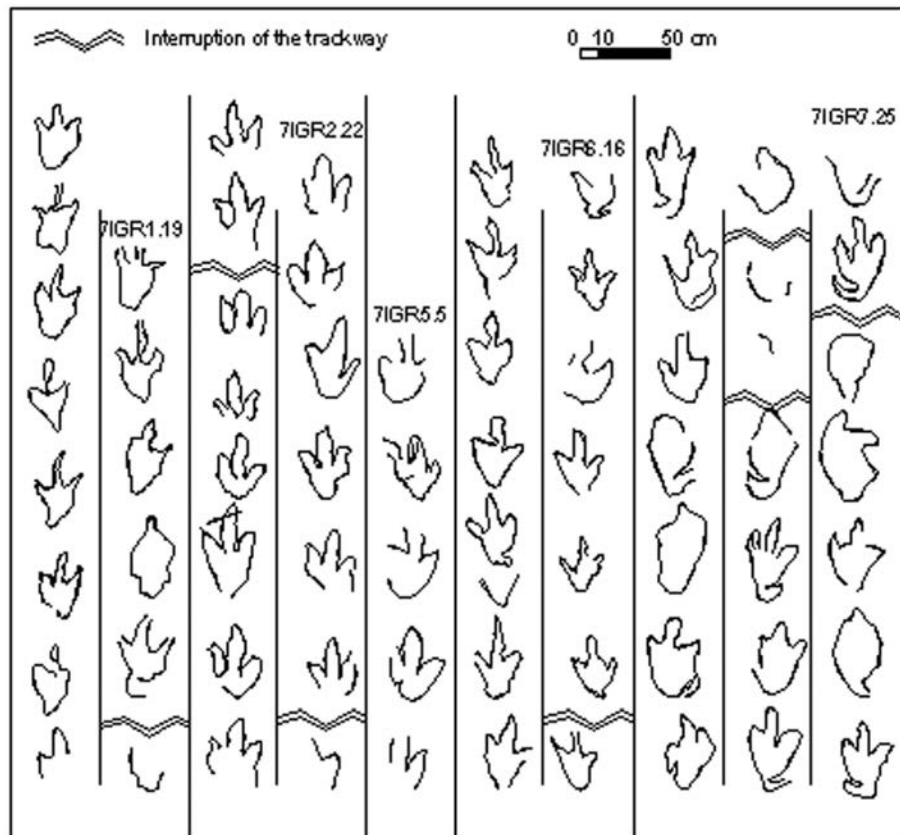


Fig. 4.- Outline of the footprints of the trackways with *Boutakioutichnium* ichnites of 7IGR site.

Fig. 4.- Línea de contorno de las pisadas de las rastrilladas con *Boutakioutichnium* de 7IGR.

measurements and relations. We have observed the difference between successive pace length, major (+) or minor (-) values, and it has been seen that in most trajectories they are irregular, compared to sequences in which they alternate regularly.

No laterality, limping or direction changes of the trackmakers (*cf.*, Lockley *et al.*, 1994; Pérez-Lorente, 2015; Masrour *et al.*, 2017) are deduced.

Most trackways (Fig. 5) have NW-SSE orientations and there are only two of 6IGR

	I	a	P	z	Ar	Lr	II^III^IV	Ap	O	h	z/h	v1	v2	(I-a)/a	Ar/a	z/l
7IGR7	45(37)	28	114	223	10	48	16-30	161	2	174	1,3	5,6	4,7	0,7	0,3	6,1
7IGR6	38(35)	26	118	231	4	34	24-37	172	2	165	1,4	6,3	5,4	0,4	0,1	6,6
7IGR5	36	29	108	212	6		10-44	165	-11	169	1,2	5,4	4,6	0,3	0,2	5,9
7IGR2	42	29	116	232	10	52		157	4	169	1,3	6,3	5,0		0,4	6,5
7IGR1	43	25	122	243	0,8	27		178								
6IGR10	37	23	99	197	10	45	10-21	157	9	173	1,1	4,6	4,2	0,7	0,4	5,3
6IGR9		24	94	187	2	29	24-19	175	7							
6IGR8	35	28	111	184			9-18			170	1,1	4,2	3,9	0,2		5,3
6IGR7	40	32	114				16-43			198				0,4		
6IGR6	41	28	101				14-14			202				0,5		
6IGR5	30	19	67	196	5	26	14-29	168	-3	161	1,2	4,7	4,2	0,7	0,3	6,1
6IGR4	44	37	135	254	1	35	14-27	178	4	215	1,2	5,9	5,0	0,2	0,4	5,8
6IGR3	39	27	113	228	6	35	5-22	168	-4	197	1,1	5,6	4,7	0,4	0,2	5,9
6IGR2	36	39														
6IGR1	39	29	221	438	-0,3	33	24-13	180	-5	183	2,3	16,5	9,1	0,2		11,3

Table I.- Average data of footprints and trackways. I, footprint length; a, footprint width; P, pace length; z, stride length; Ar, trackway deviation; Lr, trackway width; II^III^IV, interdigital angles; Ap, pace angle; O, orientation; h, acetabulum height; z/h, relative stride; v1, v2, speed (Alexander, 1976; Thulborn, 1990; Demathieu, 1986); (I-a)/a, relative footprint length; Ar/a, relative trackway deviation; z/l, relative footprint relation.

Tabla I.- Datos medios. I, longitud de la pisada; a, anchura; P, longitud de paso; z, longitud de zancada; Ar, amplitud de rastrillada; Lr, luz de rastrillada; II^III^IV, ángulos interdigitales; Ap, ángulo de paso; O, orientación; h, altura del acetábulo; z/h, zancada relativa; v1, v2, velocidad (Alexander, 1976; Thulborn, 1990; Demathieu, 1986); (I-a)/a, anchura relativa de la huella; Ar/a, anchura relativa de rastrillada; z/l, índice tipo extremidad.

whose direction is towards NE. Ten go to the SE, and their layout is subparallel (see 6IGR1-6IGR3-6IGR5 and 7IGR2-7IGR5-7IGR6). They can be interpreted as non-compact dinosaur groups of gregarious behavior (see Pérez-Lorente, 2015).

Discussion

Boutakioutichnium (Nouri *et al.*, 2011) is a theropod ichnite, perhaps a therizinosaur footprint, deduced by the hallux development and position of its proximal part. This position implies that the first metatarsal is strong, long and rotated distally to the side of metatarsal IV. The reason why some ichnites preserve a hallux print and others do not remains unknown after examining the previous traces. There are no criteria to deduce that footprints that have the digit I mark are deeper or have the metatarsal more inclined than the others. Many of the traces from the two sites have the rear part deformed when compared to the tridactyl theropod ichnites or those with a metatarsal mark. Apparently, the study surface of these ichnites is the same tracking surface, and it can be supposed that it was relatively elastic because: a) the desiccation cracks are previous to the footprints; and b) the polygons are brecciated in the bottom of the footprints.

It has been proposed that sinusoidal type of displacement may be due to the course correction due to the deviation produced by laterality of the animals (*cf.* Pérez-Lorente 2003). However, the reflection of this tendency should be translated into the sequence of alternating long and short steps varying according to a pattern. This variation pattern has not been found in this site.

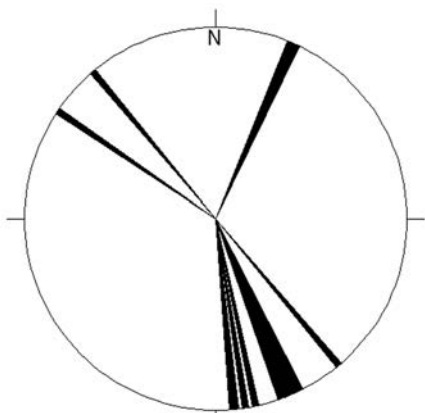


Fig. 5.- Theropod trackway orientations of 6IGR and 7IGR sites.

Fig. 5.- Orientación de las rastrilladas terópodos de 6IGR y 7IGR.

Conclusions

The study of these two sites added 199 traces to the inventory of dinosaur ichnites of the Iouaridène syncline, thus adjusting the number of footprints, within the expected number (approximately 2000) by Boutakiout *et al.* (2009).

The intercalation of tridactyl and tetradactyl footprints in trackways produced by the same trackmaker modifies the prediction of the type of theropod dinosaurs that imprinted the Iouaridène tracks. The description of the examples of these two sites suggests that caution is needed in ichnotaxonomy interpretations. This site shows the repeated fact that not only does a functionally tridactyl dinosaur produce tridactyl ichnites, that can be assigned to different ichnotaxons, but also dinosaurs with different autopods (tetradactyl) can produce ichnologically similar traces (tridactyl and tetradactyl).

The sinusoidal trackways support the hypothesis that the dinosaurs walked with this sinusoid movement. The irregularity of the patterns does not indicate that the regular sequences (alternative + $[P_n < P_{n+1}]$ and - $[P_n > P_{n+1}]$ length paces) are always congruent with the lameness or laterality of the bipedal dinosaurs.

Aknowledgements

We have to thank the members of the AME (Friends of the Enciso Museum) as well as our colleagues Latifa Ladel, Diego Castanera and Magin Murillo for the help in the field for planning and data collection. In the same way we would like to thank the extinct foundations Cajarioja and Patrimonio Paleontológico de La Rioja for the financing and means of transport of personnel and work material. We specially acknowledge the comments, notes and suggestions of the reviewers M. Masrour and D. Castanera, and the remarks of the editors. Finally, we thank the University of Rabat for the granting of research permits on the ground.

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