Crocodile tail traces and dinosaur footprints. Bathonian?-Callovian. Imilchil. High Central Atlas. Morocco

Marcas de cola de cocodrilos y huellas de dinosaurio. Bathoniense?-Calloviense. Imilchil. Alto Atlas Central. Marruecos

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ABSTRACT

Three types of ichnites from a new site discovered in Imilchil were studied and described. The structures of pes and manus prints and tail traces of tetrapods provide data to separate: real ichnites (theropod footprints and crocodile tail drag marks); and sauropod' subtraces. Most of the theropod footprints are deformed by collapse of their walls, the sauropod subtraces show the strong deformation of about ten well-stratified sedimentary levels. The surface on which we can see theropod and crocodile ichnites is the tracking surface, i. e. the original surface on which they were printed.

Key-words: *tail drag, footprints, crocodiles, dinosaurs, Imilchil megatracksite, Morocco.*

RESUMEN

Se estudian tres tipos de icnitas de un nuevo yacimiento descubierto en Imilchil. Las estructuras de las huellas de pies, manos y cola de tetrápodos proporcionan datos para separar: icnitas reales (pisadas terópodas y marcas de arrastre de cola de cocodrilos) y calcos saurópodos? La mayor parte de las huellas terópodas están deformadas por colapso de sus paredes, y las subhuellas saurópodas muestran la fuerte deformación de unos diez niveles sedimentarios bien estratificados. La superficie en la que se encuentran las huellas terópodas y las icnitas de cocodrilo son la superficie de marcha, es decir la superficie original sobre las que se imprimieron.

Palabras clave: *marcas de cola, pisadas, cocodrilos, dinosaurios, megayacimiento de Imilchil, Marruecos*

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Introduction

We present a new study on vertebrate ichnology in the Imilchil region (Morocco) where we have been prospecting since 2016 (Fig. 1). Gandini (2009) and Gierlinski *et al.* (2009) were the first to publish data on the area. So far, dinosaur footprints (theropod and sauropod of various types), crocodile and pterosaur footprints have been described (Klein *et al.*, 2018). The whole (50-60 Km^2) is considered a megatracksite (Boutakiout *et al.* 2020). In the present site we have found crocodile tail dragging traces, tridactyl theropod footprints and probably large sauropod traces.

Gandiní (2009) grouped the Outcrops of the area by "Sites" and within them by strata (A, B, C, ...). We distinguish the sites by their geographical situation, named successively as we study them. This site is No. 10 found at "site 7" of Gandini (2009), and is on the NW flank of the Ait Ali Ou Ikoud syncline, very close to the town of Tagigahcth; the symbol we have given is 7.10TAG. The coordinates of the site according to Google images are 262575 // 3567689.

7.10TAG is an outcrop of silty sandstones and limolites from the Isli Formation (Gierlinski *et al.*, 2017) whose age is Bathonian? - Callovian (Fig. 1). The appearan-

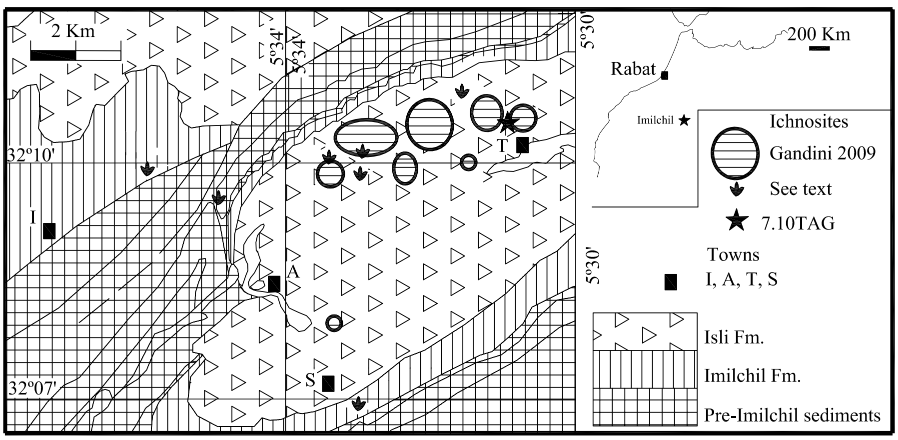

Fig. 1.- Location of Imilchil ichnological sites: Towns: A, Aït Ali Ou Ikkou; I, Imilchil; S, Sountat; T, Taghigacht.
Fig. 1.- Localización de los yacimientos icnológicos de Imilchil. Aduares de: A, Aït Ali Ou Ikkou, I, Imilchil; S, Sountat; T, Taghigacht.

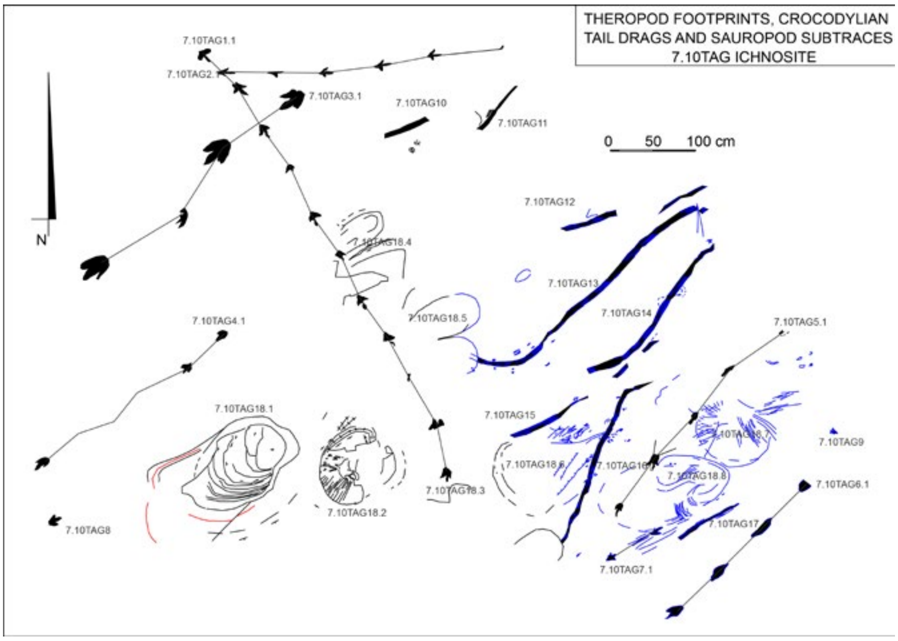

Fig. 2.-Ichnites of the 7.10TAG site.
Fig. 2.- Huelllas del yacimiento 7.10TAG.

ce of the stratigraphic sequence is like a succession of motley-colored layers that range from very light yellow green to dark brown and black. The colours of the fresh rocks are clear and greenish but they change to brown and black tones due to the ferruginous weathering patina.

Material and Method

The site occupies a surface of 56 m^2 with a N90E strike and 25ºS dip. For its reproduction, first a cross-linking with chalk of 30x30 cm of mesh light was done, and then it was photographed. The photographs have been manually restored with Adobe Photoshop and subsequently drawn on a two-dimensional AutoCAD basis. Most of the measurements have been made on that basis.

The largest bed of the 7.10TAG (Fig. 2) contains real traces of vertebrates (dinosaurs and crocodiles) and probably sauropod subtraces. No ichnogenus or ichnospecies have been identified because most of the footprints are deformed or are subtraces. (Fig. 3).

The concepts and characters used are those given by the first who gave a name to them (*cf.* Pérez-Lorente, 2015).

Ichnology

We have grouped the 7.10TAG vertebrate ichnites into: tridactyl footprints, large undertracks and tail marks.

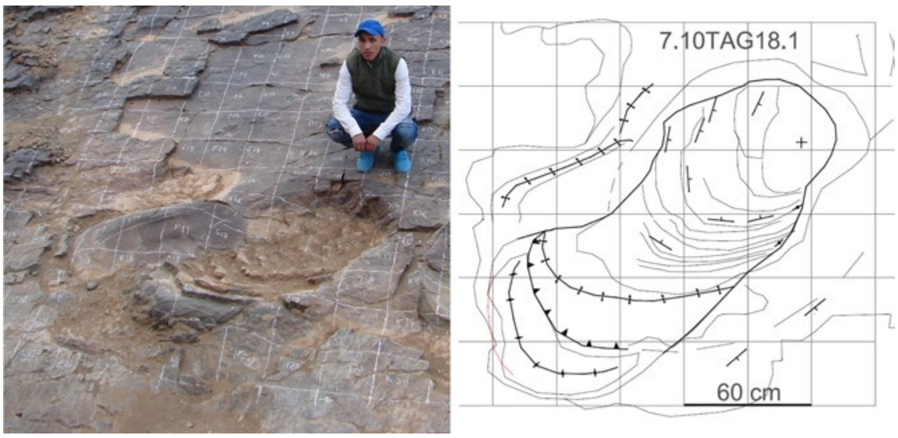

Fig. 4- 7.10TAG18.1. Photo and design of its structures. The dark lines are fractures, fold axis and symbols of bed strike and dip.
Fig. 4.- 7.10TAG18.1. Fotografía y dibujo de sus estructuras. Las líneas oscuras son fracturas, ejes de pliegue y símbolos de dirección y buzamiento de las capas.

Tridacyl footprints

There are six trackways (7.10TAG1 to 7.10TAG6), a pair of footprints (7.10TAG7) and two isolated footprints (7.10TAG8 and 7.10TAG9). The trackways are mostly complete and only 3 intermediate footprints are missing in 7.10TAG4. Except for the 7.10TAG9 footprint, which is not complete and we cannot decide if it has more than three digits, all the others are tridactyl, with relatively long digits of acuminate termination. All (except 7.19TAG8 that is on a higher level) are on the top surface of the same layer. All are theropod ichnites.

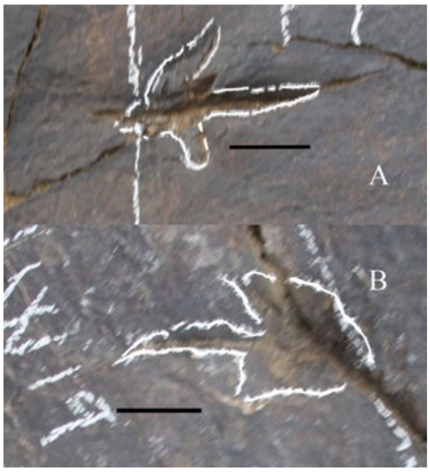

Fig. 3.- A, collapse of 7.10TAG2.5; B, Collapse and bent of 7.10TAG5.5.
Fig. 3.- A, colapso de 7.10TAG2.5; B, Colapso y torsión de 7.10TAG5.5.

The trackway 7.10TAG3 is different from the others because it has rather wider digits and longer footprints (l = 34 cm) without collapse or deformation structures. It has: a greater pace length (P = 102 cm) and stride length (z = 196 cm);and a smaller pace angle (Ap = 130º) and Sternberg ratio (z/l = 5.7). The rest of the theropod tracks are shorter (l ranges between 22 and 14 cm) and their trackways have such a large pace angle (Ap = 170 to 180º) that the stride length is very close to twice the pace length.

All footprints are narrow ([l-a] / a between 0 and 1), with very narrow trackways (Ar/a <0.5) (Ar = trackway deviation; a = width of the footprint). The average speed ranges between 3.7 and 5.5 km/ hour.

The short theropod ichnites (except 7.10TAG8) are deformed by synsedimentary collapse structures that narrow the digits and/or by compression produced by the posterior possibly sauropod subtraces (Fig. 4). The projection of digit III

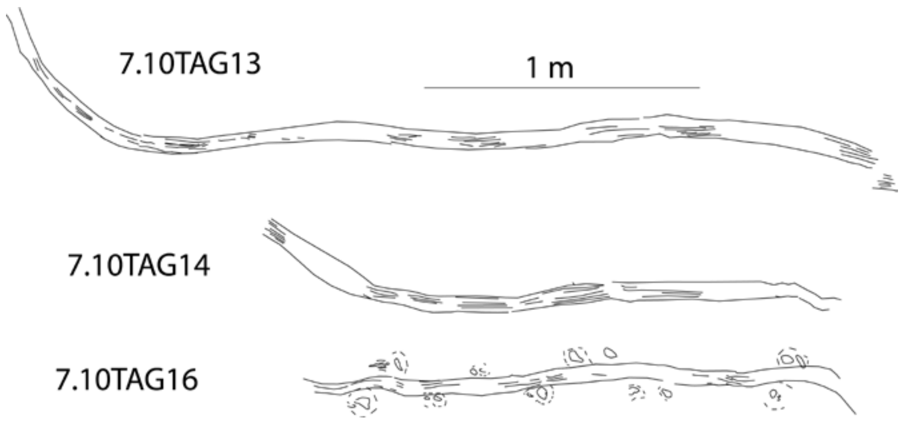

Fig. 5.- Three sinusoid tail traces. Striae and cuadruped trackway.
Fig.5.Tres marcas sinusoidales de cola. Estrías y rastrillada cuadrúpeda.

cannot be calculated because the footprints are deformed or their contours are incomplete.

Large undertracks.

At the site there are large rounded depressions that we include in group 7.10TAG18 (Fig. 2). The largest 7.10TAG18.1 measures 203x117 cm and several sedimentary levels are involved in it (Fig. 4): a) the tracking surface (SM) of the theropod footprints and the tail marks, and; b) at least 8 levels above it.

7.10TAG18.1 (Figs. 2, 4) is the most complete of the ichnites of this group. The deepest part is occupied by about 8 levels (not fractured) of more than 3 cm thick intruded in the hollow of the track. We consider them a dead zone (Allen, 1997). On the wall of the footprint those levels are cut (fractured) or folded. The walls of the footprint are from the SM top or higher levels. The edge of the footprint is an extrusion rim created by the fold of the SM or of the upper levels and form a surrounding anticline, at some points with vertical flanks.

7.10TAG18.2 is also a structure consisting of a central depressed area surrounded by a fold of SM. On the north edge the fold has vertical flanks. In this footprint, post-SM levels are not preserved. Water-escape structures are very evident in what is probably a ~~sliding~~ slide surface of deformed levels. In this and other subtraces of 7.10TAG18 there is a change in the colour tone of the rock on each side of the outline of the subtraces.

The rest of 7.10TAG18, are depressions of different depth and extension with raised edges. In 7.10TAG18.4 a zone of the surrounding fold axis has broken and an open scar is formed that runs along the hinge. Finally, in 7.10TAG18 6 there are breaks in the form of tension microfaults congruent with the sinking of the center of the footprint. They are water-escape structures in 7.10TAG18.2, 7.10TAG18.6, 7.10TAG18.7, 7.10TAG18.8 footprints.

In the NE half of the site, the SM has rounded depressions that are less deep and just as wide which we have not indicated due to the difficulty of establishing their limits and because when too indistinct it is doubtful whether the depressions correspond to subtraces. This fact has already been cited in some sites with sauropod footprints in which the depth of the footprints decreases due to the hardening of the substrate perhaps due to its lower water content. (Casanovas *et al.*, 1992; Pérez-Lorente, 2015)

Tail marks

The ichnites 7.10TAG10 to 7.10TAG17 are parallel, sigmoid bands (Figs. 2, 5, 6). The length of the bands ranges between 54 and 210 cm and their width between 2 and 7 cm. Along and inside the bands there are striae parallel to the edges. We have only seen extrusion rims in the initial part of 7.10TAG16.

Fig. 6.-Tail drag marks.
Fig. 6.- Marcas de arrastre de cola.

Hunt and Lucas (1998), Dalla Vecchia *et al.* (2000) and Kim and Lockley (2013) cited the typical structures of the marks left by the dragging of dinosaur tails *(cf.* Pérez-Lorente and Herrero Gascón, 2007), of which the following are seen in 7.10TAG: linear (continuous or discontinuous); channel shape; generally very narrow in comparison with its length; V-shaped or U-shaped section; parallel edges; straight, irregular or sinuous; walls and bottom with grooves parallel to the layout; extrusion edge. In 7.10TAG16 (Fig. 4) there are pairs of prints forming a trackway, which alternate along the tail mark. The limit line of the prints has no recognizable shape and digit marks are not distinguished. We attribute them to a trackmaker, whose tail glides over the midline of the trackway that borders on or slightly overlaps the footprints.

There are citations of tail traces without autopodial marks on tracks in the water left by crocodiles that do not rest their feet on the ground (Bennett, 1992; Lockley and Foster, 2010). The depth and degree of sinuousness of the crocodile tail trace is variable (Farlow and Elsey, 2010; Farlow *et al*, 2018) and sometimes it depends on factors such as the depth within the water to which the animal moved .

The shape of the tetrapod tail traces is varied, and Kim and Lockley (2013) have classified them as resting and locomotion (drag). Among the mesozoic resting traces there are many of bipedal dinosaurs, while among the locomotion traces they mention both quadruped and biped animals citing above all quadruped animals. In the type of high walking, whether it is the usual type of movement or if it is optional, there are no tail marks.

The tail mark of dinosaurs is abnormal (*cf.* Torcida *et al.*, 2003) and the accompanying footprints (hallux marks in theropods and manus marks in biped ornithopods) are not normal. All sauropod tail marks have been strongly questioned, except two parallel, straight and long traces not accompanied by footprints or drag marks or extrusion rims, and which are collapse structures, probably galleries (Jenny, *et al.*, 1981).

All the previous observations regarding the morphology of the ensemble (footprints and tail drag mark) are consistent with a crocodile (Lockley and Foster, 2010) that moves under water (Farlow *et al.*, 2017). Since there are no signs of footprints that accompany all 7.10TAG tail traces, we assume that these marks have been left by crocodiles that go into the water (Farlow *et al.*, 2018). The depth to which they move cannot be deduced with this data. Due to the low sinuosity of the tail mark and the position of the striae marks: either the caudal appendage would not be used as the main motor; or the animal moved slowly in the water, maybe in favour of the current. On the tracking surface there are relatively straight and asymmetric ripple marks, oblique to the direction of movement of the trackmakers, cut and deformed by the tail traces.

In this same syncline (Aït Ali ou Ikoud) several sites with crocodilomorphic traces have been found that have been associated with *Crocodylopodus* (Klein *et al.*, 2018) and with *Batrachopus* (Masrour *et al.*, 2020). The tail traces that we examine here may have been printed by the same author as those of either of the two ichnogenus.

Conclusions

A new site is described in the Imilchil tracksite with several types of footprints. The types of ichnites of 7.10TAG are produced during at least two different epochs: a first phase in which the study surface is the tracking surface of theropod footprints and drag crocodilian tail traces; and another later phase that leaves large subtracks probably sauropods.

Has been observed that the substrate in subaqueous environments can remain plastic at great depth. One of the apparent facts of the site is the produced probably sauropod subtrace deformations by folding and fracturing of the tracking surface SM, and at least of the eight upper levels. The original bottom of these subtraces is a dead zone because under what would be the sole of the autopods, the intruded levels are neither broken nor folded. Fractures are seen at the bottom of some of the print walls, but what predominates are the folded extrusion rims. There are water-escape structures on several surfaces of these subtraces.

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