

New theropod and prosauropod ichnites from Issil-n-Aït Arbi (Lower Jurassic, Central High Atlas, Morocco)

Nuevas icnitas terópodos y prosaurópodos en Issil-n-Aït Arbi (Jurásico Inferior, Alto Atlas Central, Marruecos)

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ABSTRACT

The 1AAR group of outcrops show traces of bipedal and quadrupedal dinosaurs. The bipedal ichnites have been associated with theropod and prosauropod footprints, while the quadrupedal are associated with prosauropod footprints. It is possible that some of the quadrupedal traces were sauropod footprints, but the poor preservation and the outcrop conditions do not allow us direct and appropriate observations of them. Diagnostic characters and the possible attribution of the footprints are described in this paper. Although it is not the first time that prosauropod traces are signaled from the AAR, the footprints of the present outcrops result morphologically different, probably due to reaction of mud during the formation of the ichnite.

Key-words: Theropod ichnites, prosauropod ichnites, Pliensbachian, High Atlas, Morocco.

RESUMEN

El conjunto de afloramientos de 1AAR presenta huellas de dinosaurios bípedos y cuadrúpedos. Las huellas bípedas se han asociado a icnitas terópodos y prosaurópodos, mientras que las segundas se asocian a icnitas prosaurópodos. Cabe la posibilidad de que parte de las icnitas cuadrúpedas sean saurópodos, pero la mala conservación y las condiciones de los afloramientos no permiten hacer observaciones directas ni apropiadas sobre ellas. En este trabajo se describen los caracteres determinativos y la posible asignación de las icnitas. Aunque no es la primera vez que se mencionan huellas prosaurópodos en AAR, las de estos afloramientos son morfológicamente diferentes debido probablemente al comportamiento del barro durante la formación de la pisada.

Palabras clave: Icnitas terópodos, icnitas prosaurópodos, Pliensbaquiense, Alto Atlas, Marruecos.

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Introduction

The present paper represents the second contribution on the Issil-n-Aït Arbi site (AAR), in which we describe the set of outcrops 1.2AAR to 1.4AAR. In the first paper, the 1AAR1 trackway located in the easternmost part of the site was analysed. These footprints have been assigned to *Otozoum* (Masrou and Pérez-Lorente, 2014).

Proceeding from east to west, the outcrops have been named as follows: 1.2AAR, 1.3AAR, and 1.4AAR to distinguish them from the already published. The trackways are signed with the number of the posterior part (e.g. 1.4AAR1), and the ichnites with the last ordinal number (1.4AAR1.1 is the first ichnite of the 1.4AAR1 trackway). Each isolated footprint are considered represen-

tative of a different trackway, and a corresponding posterior number is associated to those impressions (e.g. 1.4AAR5).

The trampled surface lies mostly vertically, which does not facilitate the recognition of footprint characters. The exact number of footprints cannot be counted for several reasons:

- 1) Only part of the lower footprints are reached, and in some cases with much difficulty
- 2) In two groups of chaotic footprints, there are footprints that interfere and overlap.
- 3) There are seemingly isolated ichnites surrounded by shallow holes, which must also be footprints and are not counted.

Besides prosauropod and theropod footprints, it is possible that there exist

sauropod footprints. Nowadays, it is impossible to determine. 12 trackways, two chaotic groups of footprints and some isolated footprints are described in this paper. Theropod, thyreophora and sauropod footprints of Lower Jurassic are known in other sites of the Atlas (cf. Masrou and Pérez-Lorente, 2014) but so far, in North Africa, only prosauropod prints in the 1AAR site are known.

Geographical location and geological setting

The outcrops are located on the southeast slope of the Central High Atlas (Fig. 1). The coordinates of the extreme points of outcrops are: 30R zone; eastern end X, 221238 / Y, 3,484,954; western end, X,

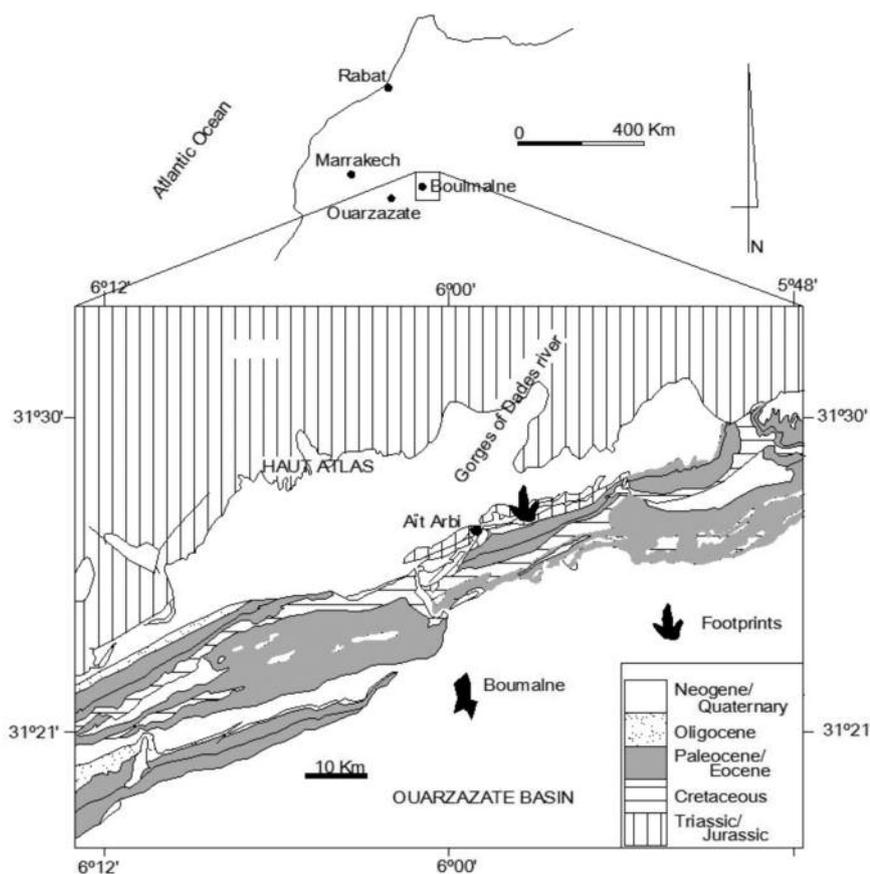


Fig. 1.- Geographic and geologic location (from Hindemeyer et al., 1977).

Fig. 1.- Situación geográfica y geológica (dibujado de Hindemeyer et al., 1977).

221140 / Y, 3484935. The area has an elongated shape, almost parallel to the bed of the ravine along approximately 100 m (Fig. 2). The strike (N070°-075°E) and dip (65°S) of strata is oblique with respect to the river bed. The youngest outcrop is 1.2AAR and the oldest one 1.4AAR. All are stratigraphically below the one that contains the 1AAR1 trackway.

The prints are seen on many resistant levels (carbonates) (Fig. 2). In some cases can not be distinguished whether they are true prints or underprints. The top of the beds is smooth in 1.4AAR; in 2AAR has mud cracks; in 1.3AAR is totally dinoturbated; and between 1.2AAR and 1.4AAR outcrops, is rugose or has unidentified hollows. Among all the carbonate rocks, which are brownish-red to light cream in colour, a clay intercalation stands out between 1.3AAR and 1.4AAR, reddish-brown to intense deep blue-green in colour.

1.3AAR is on a single level. In 1.2AAR, three sedimentary surfaces with footprints are distinguished, and in 1.4AAR probably more than two. It has not been possible to check if the footprints of 1.2AAR are of the same generation (true prints and under-

tracks). In layer sections, deformation structures produced by footprints are observable. Dinosaurs also stepped on non-emergent stratification surfaces, so the number of footprints contained in the stratigraphic sequence is much higher.

The thickness of the layers is variable but always lower than 100 cm. Carbonate strata with mud cracks (1.2AAR) comprise several layers with parallel lamination structures which produce platy fragments.

The rocks are of the Pliensbachian Arganane Formation (Ettaki et al., 2007).

Ichnology

1.AAR1

It consists of a trackway of *Otozoum moodii* Hitchcock 1847 previously described by Masrour and Pérez-Lorente (2014).

1.2AAR

Eight footprints were detected at three different levels within the same set of planar carbonate rocks affected by mud cracks. The footprints are roughly circular in outline

and deform the desiccation polygons. The bottom print surface is not flat but has holes (Figs. 3, 4) that probably must correspond to an ungual and three phalangeal pad marks, together with other major pad that may protect the metapodial-phalangeal joints.

The footprints are on inaccessible parts of the outcrop. It has only been possible to examine 1.2AAR1 (Figs. 3, 4), which is positioned in the lowest part of the trampled surface (Fig. 2). They are large (60x50 cm) and probably tetradactyl footprints. The bottom of the footprint is divided into three portions, the front portion with marks of digit pads; the central depression that is the deepest; and the posterior portion. The contours of the digital pads are rounded, one per digit on two of them, and two pads on the third digit. Pad marks in three digits are distinguished, but it is not possible to say if the most elongated is formed by the coalescence of two or more. There are no marks of sharp nails.

The central portion must match the phalangeal-metatarsal pad, and possibly the posterior portion matches with a tarsometatarsal pad at the same manner as other prosauropod footprints (cf. Rainforth, 2003). It is not possible to say if there is a fourth digit because sediments cover the right distal part of the ichnite.

The eight ichnites of 1.2AAR are large (> 40 cm) and about the same size. No small footprints are recognized, so we assume they are all pes prints. The only criteria for classification are the number and shape of digits and the shape of pes. They have been associated with prosauropod trackmaker through a process of elimination (see below).

1.3AAR

It is a group of 80 deep footprints, almost all drawn from photographs (Fig. 2). The lower part of the outcrop is highly deformed (dinoturbation) by pes movements. The footprint depths reaches 30 cm, so entirely pass through the layer. The best preserved footprints in the lower part of the outcrop -in which direct structures remain undeformed or only slightly deformed- are 1.3AAR1 and 1.3AAR2 (Fig. 3).

The second (1.3AAR2) is somewhat smaller. Its contour line is not coincident with any of the known prints. It may be a different design of a partly deformed ich-

nite. The footprint consists of three rounded pad marks placed at the distal end of three digits. The rear part also shows a hollow left by other pad, which is substantially larger than the digital pads. Adjacent and in contact with the footprint that two hollows that may belong to the same footprint appear. In this case, it would represent a tetra or pentadactyl ichnite similar to 1AAR1 footprints.

1.4AAR

Five groups of ichnites are identified (Fig. 1) separated by spaces without tracks, and an isolated ichnite (1.4AAR12). The study surface is fractured and partly eroded. It is probable that the footprints are printed in several tracking surfaces. In this outcrop, four types of ichnites are distinguished, grouped in: a group of tridactyl footprints (from 1.4AAR1 to 1.4AAR12); two groups formed by a trackway 1.4AAR13 and 1.4AAR14; and the group 1.4AAR15. In the first group 10 trackways (46 footprints) and two isolated footprints with the same theropod characters are distinguished. For their description, two footprints are analysed in which direct measures have been taken, (1.4AAR1.1 and 1.4AAR12).

1.4AAR1.1 is a right tridactyl footprint, with relatively long, separated and acuminate digits. It is at the beginning of the 1.4AAR1 trackway. Lateral constrictions are observable in the contour line of the digits. It is a large theropod footprint (28x24 cm). The average pace is 100 cm and the stride is 204 cm. According to the formulas of Alexander (1976), Thulborn (1990) and Demathieu (1986), the inferred speed for this dinosaur ranges between 6.4 and 4.9 km/h.

1.4AAR12 is also probably a right theropod footprint. It has very salient heel and bottom striae due to deformation during the print formation (Boutakiout *et al.*, 2006). The footprint length is 36 cm and the width is 27 cm.

The 1.4AAR13 and 1.4AAR14 trackways cannot be measured because they are inaccessible. It is noteworthy that several footprints from 1.4AAR13 are tridactyl and probably of the same type as those described before (1.4AAR1 to 1.4AAR12). It differs at least for his much wider trackway.

The 1.4AAR14 trackway is made up of large footprints, that form an apparently

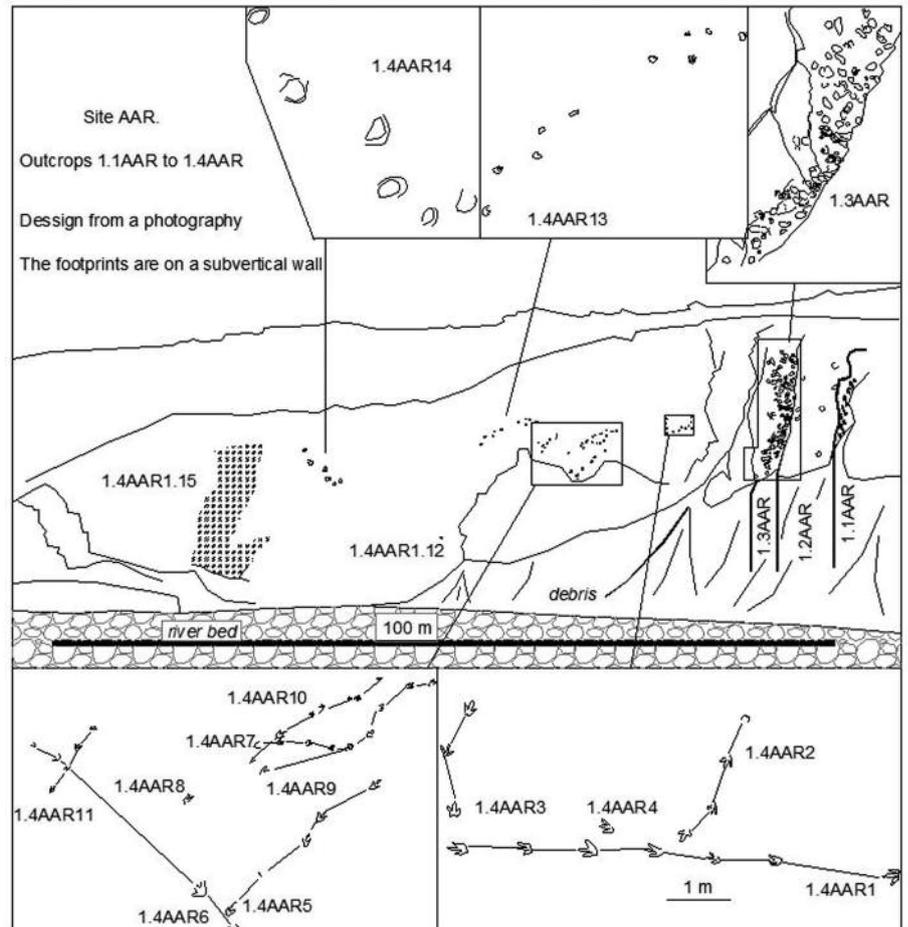


Fig. 2.- Relative location of outcrops and footprints. There contains unscaled areas.

Fig. 2.- Posición relativa de los afloramientos y de las icnitas. Hay sectores sin escala.

biped or quadruped trackway with overlapping footprints. In several footprints an exterior (discontinuous) line is drawn, parallel to the contour line whose explanation is not known. No extrusion rims appear because elevation of the study surface (Requeta *et al.*, 2006-7) is not observed.

Finally, there is an aggregate of footprints (1.4AAR15) that occupies a band that transversely crosses the stratum. The footprints are deformed and no character is recognized that allows us to associate them with a group of dinosaurs. There are no criteria to eliminate sauropod dinosaurs as possible trackmakers.

Prosauropod footprints 1.2AAR and 1.3AAR

It must be ensured that the prosauropoda attribution is firmly founded because this type of footprint has not been cited in North Africa, except at Issil-n-Aït Arbi. The characters that suggest this assignment are reported below. By their age

(Lower Jurassic) certain quadrupeds or semibiped dinosaurs (ornithischians) cannot be the trackmakers.

Both types of footprints (1.2AAR and 1.3AAR) have several characters that are diagnostic. First, the bottom of the footprint is divided into three parts equivalent to the digits, metatarsophalangeal and tarsometatarsal portions. Secondly, they are footprints with four identifiable digits sub-parallel to the foot elongation. The digit pads are relatively large, and have a rounded distal end.

These characters distinguish them from sauropod, theropod and ornithopod footprints. The two groups of potential dinosaurs of this age whose footprints have a clear metatarsus mark would be prosauropods and thyreophorans. From this period a thyreophoran footprints (Hadri *et al.*, 2007) and prosauropod footprints (1AAR1) have been cited in the area. The thyreophoran footprints are tridactyl, but in their digits, usually divergent, only a rounded pad is discernible. Therefore we

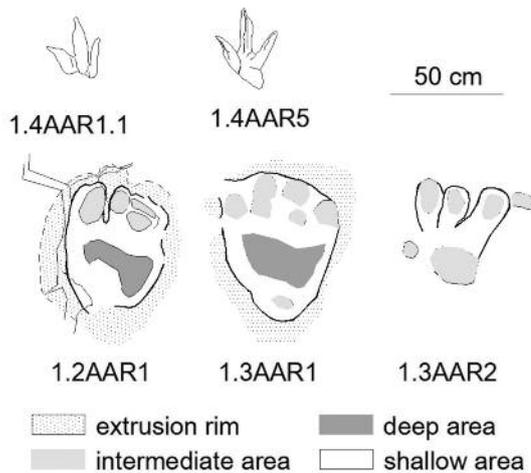


Fig. 3.- Representative footprints.
Fig. 3.- *Ichnitas representativas.*



Fig. 4.-1.2AAR1 ichnite.
Fig. 4.- *Ichnita 1.2AAR1.*

assign the footprints of both outcrops (1.2AAR and 1.3AAR) to prosauropod ichnotaxa as *Pseudotetrasauropus* (cf. D’Orazi Porchetti and Nicosia, 2007), or more likely *Otozoum* (cf. Rainforth, 2003).

Behavior

As is often seen in large footprint outcrops, dinosaurs are grouped by type and areas. In 1AAR the same thing happens. It

is, however, questionable whether the AAR groups are due to the environment (natural barriers, water spots, favourable places, etc) or to gregarious behaviour. It is true that the passage of herds leave footprints in chaotic groups in delimited strips of land. For this reason, one can only assume that the 1.3AAR ichnites should be a herd of prosauropods; whereas that of 1.3AAR14 might be due to the passage of a herd of dinosaurs, of unknown affinity.

Conclusions

New theropod and large prosauropod footprints are described in a Moroccan site characterized by diversity of footprints and their groupings. The tracks represent to date the only evidence that there were prosauropod dinosaurs in the Lower Jurassic of the Atlas Mountains.

Though sites with groups of prosauropod footprints have been already described, they all belong to few individuals and none contain chaotic groups, perhaps by footprint preservation and/or different substrate conditions. It is possible, therefore, that this site (1AAR) contains the footprints not only of isolated individuals or those in separated groups (slightly dense herds), but also of one or two herds of prosauropod dinosaurs.

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