



On small quadrupedal ornithopod tracks in Jurassic-Cretaceous transition intertidal deposits (El Castellar, Teruel, Spain)

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ABSTRACT

The study of an undescribed part of the El Pozo tracksite in El Castellar (Teruel, Spain) has revealed two new trackways made by small ornithopods showing new evidences of basal ornithopod pes and manus track morphologies in the Jurassic-Cretaceous transition. The site lies within the Villar del Arzobispo Formation, which was deposited during the Tithonian-Berriasian in an environment under the influence of tides. The pes tracks are small tridactyl tracks, the digits are similar in size, and the heel is open and rounded. The presence of oval manus tracks in front of the tridactyl tracks in one of the trackways confirms that the dinosaur was a quadrupedal. Probably, the trackmaker dinosaur is a representative of the dryosaurid or of the basal Ankylopollexia clades. These tracks are smaller than those described for the Las Cerradicas site, also located in Teruel and in the same formation; consequently, these tracks from El Pozo site constitute some of the smallest ornithopod trackways with quadrupedal locomotion ever described in the world. In addition, in the same tracksite bed, there are some poorly preserved tracks attributed to big quadrupedal dinosaurs.

Keywords: Ornithopod, tracksite, Villar del Arzobispo Formation, Tithonian-Berriasian, Iberian Range.

RESUMEN

El estudio de una parte no descrita del yacimiento de icnitas de El Pozo en El Castellar (Teruel, España) revela dos rastros producidos por pequeños ornitópodos que aportan nuevos datos acerca de la morfología de las huellas de pies y manos de ornitópodos basales en la transición Jurásico-Cretácico. El yacimiento se sitúa en la Formación Villar del Arzobispo, que se depositó durante el Titoniense-Berriasiense en un ambiente bajo influencia mareal. Las icnitas del pie son pequeñas huellas tridáctilas, con los dígitos de tamaño similar y el talón redondeado. La presencia en uno de los rastros de huellas ovaladas de manos delante de las tridáctilas confirma que el dinosaurio era cuadrúpedo. Probablemente, el dinosaurio productor es un representante del grupo de los dryosáuridos o de los Ankylopollexia basales. Estas huellas son menores que las descritas en el yacimiento de Las Cerradicas, también situado en Teruel y en la misma formación; en consecuencia, las icnitas del yacimiento de El Pozo forman parte de los rastros de ornitópodos con locomoción cuadrúpeda más pequeños descritos hasta el momento. Además, en la misma capa se encuentran algunas huellas mal conservadas atribuidas a grandes dinosaurios cuadrúpedos.

Palabras clave: Ornitópodos, yacimiento de huellas, Formación Villar del Arzobispo, Titoniense-Berriasiense, Cordillera Ibérica.

1. INTRODUCTION

The Villar del Arzobispo Formation bears numerous dinosaur ichnite and vertebrate bone sites, some of which are type localities for new dinosaur taxa. Almost thirty dinosaur tracksites have been recorded in this formation in the Province of Teruel, Spain (Cobos, 2011; Alcalá *et al.*, 2012) and one of them, CT-1 (El Castellar tracksite in the El Castellar municipality) is the type locality for the ichnospecies *Deltapodus ibericus* Cobos, Royo-Torres, Luque, Alcalá & Mampel, 2010, which has been attributed to a stegosaurian trackmaker. Also, other tracks registered in the aforementioned formation have been attributed to a sauropod trackmaker (possibly a diplodocoidea), big sized theropods and thyreophorans at Ababuj AB-1 (Ababuj, Teruel) site (Alcalá & Martín, 1995; Royo-Torres, 2009; Alcalá *et al.*, 2012); at Aguilar 3 AG-3 (Aguilar del Alfambra, Teruel) three trackways attributed to stegosaurid trackmakers and five trackways made up of small tridactyl tracks attributed to bipedal dinosaurs, have also been described (Mampel *et al.*, 2010-2011). In addition, there are tracks attributed to titanosauriforms at the Las Cerradicas site (Galve, Teruel) (Canudo *et al.*, 2008; Castanera *et al.*, 2011, 2012), where theropod and ornithopod trackmakers have been described (Pérez Lorente *et al.*, 1997; Cobos *et al.*, 2008; Lockley, 2009a; Castanera *et al.*, 2013).

Surrounding El Castellar there are several palaeontological sites -totalling almost 50- which have provided both: direct remains (skeletal elements) and ichnites (tracks) of dinosaurs. The record of ichnites is characterized by tracks attributed to quadrupedal (sauropod, stegosaurid and ornithopod) and bipedal (theropod) dinosaurs. Three main dinosaur tracksites lie within the Villar del Arzobispo Formation, which was deposited during the Tithonian-Berriasian in an environment under tidal influence. Among the several hundreds of documented tracks at El Castellar we can highlight a trackway left by a large theropod (Alcalá *et al.*, 2014), and at least another made by a stegosaurid (the holotype of *Deltapodus ibericus*, Cobos *et al.*, 2010) both at site CT-1; and some of the largest sauropod tracks ever found in the Iberian Peninsula at site CT-3 and the El Mirador site. The characteristics of some prints suggest they may have been made by turiasaur eusauropods (Cobos *et al.*, 2008; Royo-Torres, 2009; Alcalá *et al.*, 2014).

The Villar del Arzobispo dinosaur tracksites in El Castellar were first reported by Alcalá *et al.* (2003), and partially described by Cobos *et al.* (2008, 2010, 2012), Royo-Torres (2009) and Alcalá *et al.* (2014). The general characteristics of the deposit have been described by Alcalá *et al.* (2014), who pointed out that all three sites (CT-1, CT-2, CT-3) contain well preserved tracks belonging to herbivorous and carnivorous dinosaurs, as well as a number of trackways. That paper describes the relationships between the sedimentary features at these sites and the

characteristics of the tracks there recorded, and attempts to determine which sedimentological conditions best favour track formation and preservation, because sediment composition, structure and grain size could give rise to different track shapes and degrees of preservation. Indeed, the El Castellar sites show slightly different sedimentary features, and in fact, the CT-1 tracksite shows several substrate consistencies even within a single layer.

The facies of the El Castellar sites correspond to siliciclastic-carbonate tidal environments belonging to the Villar del Arzobispo Formation (middle Tithonian-lower Berriasian) (Mas *et al.*, 1984; Aurell *et al.*, 1994; Bádenas *et al.*, 2008-2009). This formation consists of limestones, sandstones and red claystones. Its maximum recorded thickness is 550 m in the type section, and it is more than 400 m thick in the El Castellar area (Aurell *et al.*, 1994).

The characteristics of the Tithonian-Berriasian intertidal deposits at El Castellar suggest that sediment grain size and water content were the key factors which determined the recording of dinosaur tracks and trackways. The micritic mud derived from the pellets (which are common in some tracksites, aggregated and imbricated in fine layers, probably transported by currents) is a good track recorder, and preserves the details of tracks when it contained some water; on the contrary, biofilms seem not to have provided any special cohesion to the sediment surfaces of the El Castellar tracksites, and probably played no significant role in preventing the collapse of the track walls (Alcalá *et al.*, 2014).

2. DESCRIPTION

The El Pozo CT-2 tracksite outcrops in small scattered patches of a limestone layer near El Castellar village (Fig. 1). The tracks are distributed at the upper part of a limestone stratum stretching more than 500 m². There are at least three different limestone track surfaces: 1CT-2 the lower, 2CT-2 the intermediate and 3CT-2 the upper (Fig. 2). Just one of these dinosaur track assemblages, more specifically the outcrop 3CT-2, has not been described previously, in spite of having already been cited by Cobos *et al.* (2008), who assigned several manus and tridactyl pes prints to small quadrupedal ornithopods.

The 3CT-2 outcrop was found while undertaking conservation tasks carried out in 2007 at the El Pozo CT-2 site by Escuela Taller de Restauración Paleontológica II del Gobierno de Aragón and Fundación Conjunto Paleontológico de Teruel-Dinópolis. The cleaning of the site unveiled a new outcrop containing 25 dinosaur tracks on a grey limestone surface of nearly 4 m², with an average direction of N165E and 5°W dip, which was covered by vegetable matter. It is included in a zone declared an Asset

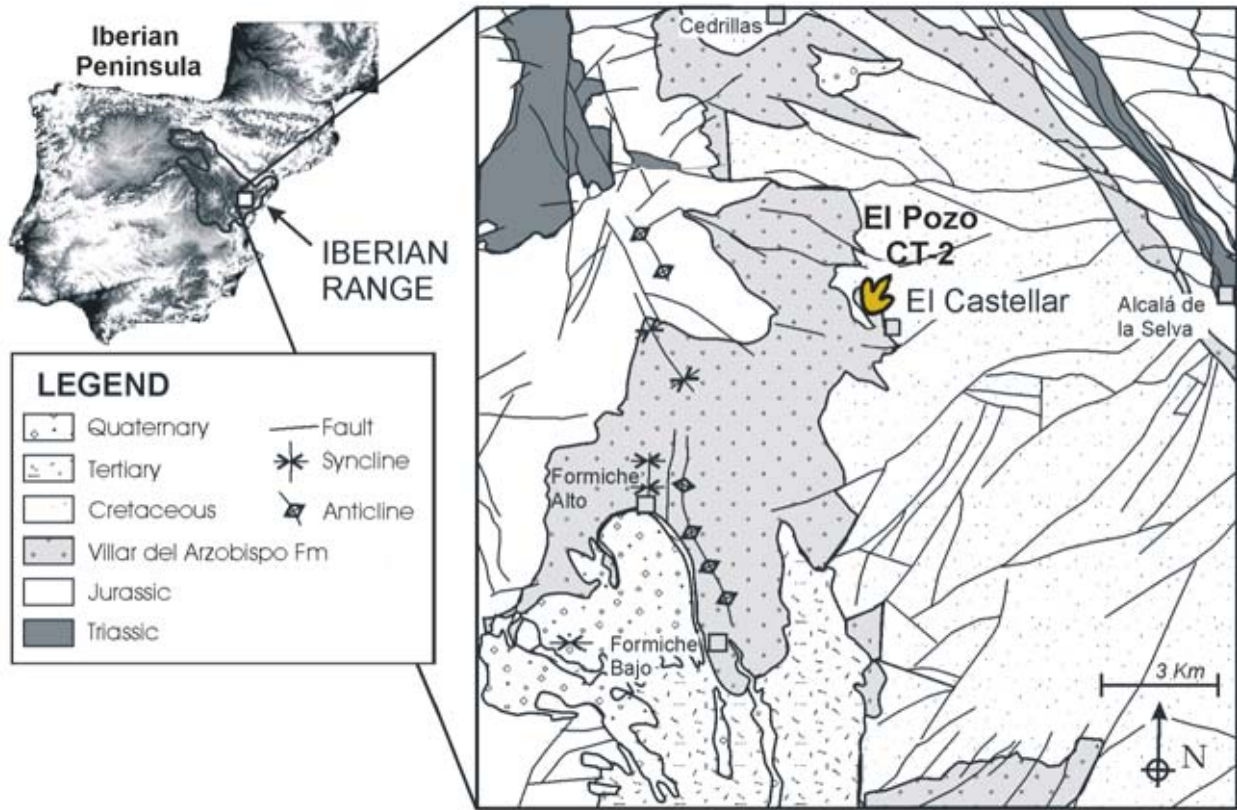


Figure 1. Placement of the El Pozo CT-2 site (El Castellar, Teruel, Spain) containing the 3CT-2 outcrop, which is studied in this paper.

of Cultural Interest (*Bien de Interés Cultural*, BIC) in the category “*Conjunto de Interés Cultural*”, Palaeontological Zone, by Gobierno de Aragón in 2004. The El Castellar 3CT-2 dinosaur tracksite was surveyed and the dimensions and distributions of tracks recorded using a Trimble 5600 Plus topographical total station. The data gathered were then mapped using ArcView software (Fig. 3). This small part of CT-2 was covered to avoid damage, and casts of the tracks are held at the *Museo Aragonés de Paleontología Fundación Conjunto Paleontológico de Teruel-Dinópolis*.

This paper aims to characterize the dinosaur tracks from 3CT-2 outcrop in order to widen the existing information on quadrupedal trackways attributed to small sized ornithopod trackmakers, as this kind of trackways is scarce in the fossil record (Lockley & Meyer, 1999) and even more during the Jurassic-Cretaceous transition.

We can see some few large isolated oval tracks (corresponding to manus and pes poorly preserved), an a group of small tracks composed by: a trackway with an association of pairs of tridactyl pes and oval manus, a tridactyl trackway made up of four consecutive tracks, and several tracks from small tridactyl pes and small isolated oval manus. We focus on the trackway with three consecutive very small pairs of tridactyl pes associated with rounded manus (measurements in Table 1). These are

smaller than those of the quadrupedal trackway attributed to the small ornithopod described from Las Cerradicas, Galve, Teruel, by Pérez-Lorente *et al.* (1997).



Figure 2. General view of the El Pozo CT-2 site with its three different levels (modified from Alcalá *et al.*, 2014). Notice the placement of 3CT-2, covered to favour its preservation.

Table 1. Measurements (in cm) of the best preserved tracks and trackways recognised in 3CT-2. Abbreviations: L, track; W, track width; PL, pace length; SL, stride length; ANG, pace angulation; eTW, external trackway width.

EL POZO 3CT-2	L	W	L/W	LII	LIII	LIV	II^III	III^IV	PL	SL	ANG	eTW
3CT-2-2p	11.8	-	-	8	11	-	-	-	28	-	156	10
3CT-2-3p	11.5	10	1.15	10	11	10.5	26	29	28	55	154	9
3CT-2-3m	3.5	3	1.16	-	-	-	-	-	-	-	-	-
3CT-2-4p	15?	10?	1.5?	10	13.5	11	19	24	24	51	148	10
3CT-2-4m	4	2	2	-	-	-	-	-	-	-	-	-
3CT-2-5p	14	11.5	1.2	11	13	9	24	29	24	46	-	9
3CT-2-5m	4	4.1	0.9	-	-	-	-	-	-	-	-	-
3CT-2-8p	16	12	1.3	12	16	11	35	24	-	-	-	-
3CT-2-13p	17	13.5	1.2	9	17	9	32	30	43	-	153	-
3CT-2-16p	17	12	1.4	14	17	13	26	21	52	94	-	-
3CT-2-19m	15?	26	0.6?	-	-	-	-	-	-	-	-	-

Within the first group -isolated large tracks- three oval tracks, partially preserved, corresponding to pes (3CT-2-20p; 3CT-2-21p and 3CT-2-22p) and a manus track (3CT-2-19m) with half moon shape, broader than long and with digit I (pollex) slightly marked (Fig. 3) have been found. All represent undetermined quadrupedal dinosaurs.

The most interesting trackway is made up of eight small tracks (six of them associated in pairs of tridactyl pes-oval manus) (3CT-2-1p; 3CT-2-2p; 3CT-2-3p; 3CT-2-3m; 3CT-2-4p; 3CT-2-4m; 3CT-2-5p and 3CT-2-5m; Figs 3, 4). Three consecutive pairs of tridactyl pes-oval manus are outstanding in this trackway. The pes tracks bear a rounded posterior ridge. The two best preserved tridactyl tracks show L/W 1.15 (3CT-2-3p) and 1.2 (3CT-2-5p) values. The digits are short and broad with

a rounded to slightly pointed end (3CT-2-5p) although it is not completely sharp. Their degree of preservation allows us to distinguish the phalangeal pads in some of the tracks (especially 3CT-2-5p) and rounded, symmetric heel pads. However, hallux traces have not been identified in pes tracks. Following Lockley (2009b), the inward rotation of the pes observed in 3CT-2 trackways and the rounded, symmetric heel pads are typical features of ornithopod trackmakers. Regarding their measurements (Table 1), pes are longer (11.5-14.0 cm) than broad (10.0-11.5 cm) and digit III is slightly longer (11.0-13.5 cm) than digits II (8.0-11.0 cm) and IV (9.0-11.0 cm). The manus tracks display oval morphologies and are much smaller than the pes. The fact that the anterior (oval or sub-rounded) and posterior (tridactyl) autopod

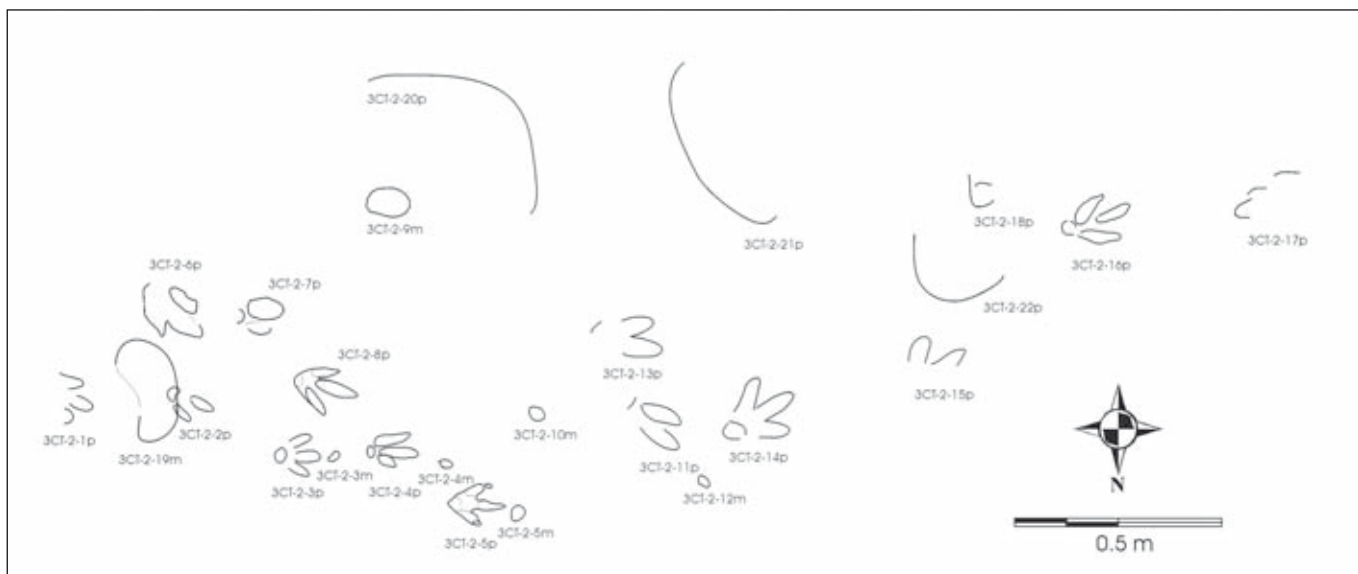


Figure 3. Cartography of the dinosaur tracks from 3CT-2 outcrop (El Pozo CT-2 site).

tracks are found associated appears decisive for assigning them to a quadrupedal trackmaker (an ornithopod, most likely), although the tridactyl tracks, looking at them in isolation, present some characteristics which resemble, in a convergent way, theropod pes (as in Las Cerradicas; Lockley, 2009a, b). There are also two isolated tracks with their morphology and size similar to those aforementioned manus and possibly produced by the same ornithopod (3CT-2-10m and 3CT-2-12m). There is, as well, a badly preserved tridactyl trackway made up of four tridactyl tracks (3CT-2-13p; 3CT-2-15p; 3CT-2-16p and 3CT-2-17p) with morphology and size similar to the aforementioned trackway; but we have to stress that the manus tracks are not associated. The best preserved of the four prints (3CT-2-16p) shows a 1.4 L/W value. The digits traces bear a slightly pointed end, although it is not completely sharp.

Finally, there are some isolated tridactyl tracks (3CT-2-6p; 3CT-2-7p; 3CT-2-8p, 3CT-2-11p, 3CT-2-14p, 3CT-2-18p) with different degrees of preservation. 3CT-2-8p (Figs 3, 4) is a well preserved tridactyl pes with L/W=1.3 where digit III is a bit longer (16 cm) than digits II (12 cm) and IV (11 cm). The absence of manus tracks association and the occasional overlapping of morphologies between theropod and ornithopod tracks leaves the attribution to a definite trackmaker uncertain, although the similar characteristics of these tridactyl tracks to the quadrupedal trackway ones point to the fact that they belong to the same ornithopod trackmaker.



Figure 4. Ornithopod tracks details: 3CT-2-8p (marked as 5); 3CT-3-3p and 3CT-3-3m (marked as 6); and 3CT-2-4p and 3CT-2-4m (marked as 7).

3. DISCUSSION

The typical characteristics used to distinguish theropod from ornithopod trackmakers are not well defined when identifying small tridactyl tracks (Marty, 2008; Lockley 2009b; Castanera *et al.*, 2012). However, the presence of tridactyl tracks, with digits of a similar size and an open and rounded heel are typical features of ornithopod dinosaurs (Sarjeant *et al.*, 1998). Besides, the identification of trackways composed by oval manus tracks in front of the tridactyl pes -proving that the trackmaker was quadruped-demonstrate they cannot confidently be assigned to a theropod trackmaker but may represent ornithopod dinosaurs (Norman, 1980; Sarjeant *et al.*, 1998). The register in 3CT-2 of trackways composed just by hind limb tracks showing identical morphologies to those of the tridactyl tracks from the 3CT-2 quadrupedal trackways allows us to confidently attribute them -in spite of being a little bit larger- to the aforementioned ornithopod trackmaker.

The quadrupedalism with tridactyl pes and presence of manus tracks was proposed for the Styrcosterna trackmakers by Carrano & Wilson (2001). Nevertheless, the presence of nail marks on II-IV digits in hooves, characteristic of this clade (Carrano & Wilson, 2001) is not clearly visible in the tracks from the El Pozo site: some marks are a bit sharp and others a bit round. Due to this variation, it is difficult to include the trackmaker within the Styrcosterna clade, thus it is more sensible to assign it to a dryosaurid or to a basal Ankylopollexia.

To compare these tracks with the direct remains we have to point out that the register of ornithopod remains found in the Villar del Arzobispo Formation consist of a tooth, an ungual phalanx and a partially articulated hind left limb from Riodeva municipality (Royo-Torres *et al.*, 2006; Gascó *et al.*, 2013), three vertebral centra from the Cerrito del Olmo site in Alpuente, Valencia (Pereda-Suberbiola *et al.*, 2009) and an isolated tooth from the “By Pass” site also in Alpuente, Valencia (Suñer & Martín, 2009). In addition, cranial and postcranial ornithopod remains have been described from the Tithonian-?Berriasian Ciria Formation of Berdejo, Zaragoza (Royo-Torres *et al.*, 2012). These Spanish Tithonian-Berriasian ornithopod remains were attributed to indeterminate basal ankylopollexians (Pereda-Suberbiola *et al.*, 2009; Royo-Torres *et al.*, 2012; Gascó *et al.*, 2013) which could be related to the basal ankylopollexian *Draconyx loureiroi* from the Portuguese Tithonian of Lourinhã (Mateus & Antunes, 2001), and to the camptosaurids described from the Portuguese Tithonian (Malafaia *et al.*, 2010) and from the Spanish Berriasian (Pereda Suberbiola *et al.*, 2006). The fact that basal Ankylopollexia direct remains are present would be consistent with the ichnological register from the El Pozo site (Cobos *et al.*, 2008) and other tracksites in the Villar del Arzobispo Formation, such as Las Cerradicas (Pérez-Lorente *et al.*, 1997).

Another primitive ornithopod, closely related to *Dryosaurus*, has also been identified in the Tithonian Andrés site (Malafaia *et al.*, 2010). Dryosaurids exhibit unusually specialized and narrow feet (Norman, 2004) and according to the size of their pes (length 10-15 cm; see fig 19.13 in Norman, 2004) it could also be a possible trackmaker of the described tracks. Thus, the 3CT-2 trackmaker would be a quadrupedal basal ornithopod: possibly a dryosaurid or a basal member of Ankylopollexia (but out of the Styrcosterna clade).

The Las Cerradicas site contains more than a hundred mapped tracks. The first description of the site, carried out by Pérez-Lorente *et al.* (1997), describes one of the trackways as belonging to an ornithopod and other three trackways, whose pes share similar characteristics, to possible ornithopods or theropods trackmakers (Cuenca-Bescós *et al.*, 1997). The attribution of the three doubtful trackways to theropod trackmakers was later confirmed by Pérez-Lorente (2004, 2009) and Canudo *et al.* (2005, 2008, 2010). Concerning this matter, Alcalá (2006) mentions that there is a diversity of criteria on the attribution of these three trackways to theropod or ornithopod tracks, in spite of the fact that in the original study by Pérez-Lorente *et al.* (1997) manus tracks are already mapped in the trackways attributed to theropods. Even more, the identification of the three parallel trackways as being left by theropods led some researchers to propound a gregarious behaviour of carnivorous dinosaurs during the Tithonian-Berriasian transition, specified in scientific papers (Pérez-Lorente, 2004, 2009; Canudo *et al.*, 2008, 2010; Castanera *et al.*, 2012) and in the information provided to explain the characteristics of the site to the public when it was open to the visitors by Gobierno de Aragón.

In spite of keeping in mind all the aforementioned facts, the four trackways with tridactyl pes from Las Cerradicas have been undoubtedly attributed to quadrupedal ornithopod trackmakers several times (Royo-Torres & Cobos, 2007; FCPTD-IDPI, 2009; Lockley, 2009a; Cobos, 2011; Alcalá & Cobos, 2012; Castanera *et al.*, 2013). The lack of a complete pes-manus pairs association in some trackways from Las Cerradicas would be the consequence of the differential preservation of the ornithopod manus tracks, as detail Castanera *et al.* (2013).

The presence of tridactyl pes associated with manus tracks would be an evidence to propose an ornithopod trackmaker (Carrano & Wilson, 2001) and it forces to rule a theropod trackmaker out, disregarding the interpretation that small theropods were gregarious in Galve during the Tithonian-Berriasian transition.

4. CONCLUSIONS

This is the first time that the dinosaur tracks from the El Pozo 3CT-2 outcrop are described. It is placed in the Villar del Arzobispo Formation (Tithonian-Berriasian) near El Castellar village (Teruel). Among the 25 recognised tracks there is an outstanding trackway made up of three consecutive pairs of tridactyl pes with their corresponding associated oval manus which is assigned to an ornithopod trackmaker with quadrupedal habits. The interest of the finding lies in the fact that the ornithopod manus tracks are scarce, and even scarcer in the case of small sized ornithopods, from the Jurassic-Cretaceous transition zone. These are some of the smallest quadrupedal ornithopod tracks ever described in the world.

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