





El Barrancazo: a new locality of possible semi-aquatic turtle tracks from the Upper Triassic of Cortes de Pallás (Eastern Iberia)

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Abstract

This work describes the new vertebrate tracksite named El Barrancazo, located in Cortes de Pallás (Eastern Iberia). This new site turns this area into the one that concentrates the largest number of vertebrate footprints from the Upper Triassic of Iberia. The footprints are presented as natural casts distributed in isolated blocks belonging to the Manuel Formation (K2, Keuper facies), deposited during the Carnian Pluvial Episode (Late Triassic). The blocks come from two beds of the same outcrop. The tracks are made up of sub-parallel digital impressions, displaying occasional curved traces, often without forming a complete outline, and showing a set of features such as lateral and posterior overhangs, longitudinal striations or digital reflectures, among others. These features, taken together with the sedimentological analysis carried out, suggest that animals moving in totally or partially buoyant conditions in a fluvial environment produced most of these tracks. The size and morphology of these paleoichnological impressions suggest that they were probably produced, in some cases, by turtles, adding to the understanding of the paleoenvironmental and paleofaunistic conditions of the Late Triassic of Iberia during the Carnian, a key period in the evolution of different groups of continental vertebrates. In this paper we show the comparative study of the three sites described to date in Cortes de Pallás and an analysis of the interplay of trackmaker organism, animal behavior and substrate in the resulting morphology of tracks made under subaqueous conditions.

Keywords Paleoichnology · Turtles · Swimming tracks · Carnian Pluvial Episode · Late Triassic · Iberia

El Barrancazo: un nuevo yacimiento de icnitas de tortugas semiacuáticas del Triásico superior de Cortes de Pallás (Este de Iberia)

Resumen

En este trabajo se presenta el nuevo yacimiento del Barrancazo, situado en Cortes de Pallás (Este de Iberia). Con este hallazgo esta área se convierte en la que concentra el mayor número de icnitas de vertebrados del Triásico superior en Iberia. Las huellas aparecen como moldes distribuidos en varios bloques aislados que proceden de la Formación Manuel (K2, facies Keuper), depositada durante el Evento Húmedo del Carniense (Triásico superior). Los bloques proceden de dos capas del mismo afloramiento. Las huellas consisten en impresiones digitales subparalelas, en ocasiones curvas y sin mostrar, a menudo, un contorno cerrado. Contienen, entre otros, rasgos como flexuras digitales, proyecciones laterales y posteriores y estrías longitudinales. Estos rasgos, junto con el análisis sedimentológico realizado, sugieren que las huellas fueron producidas por animales que se desplazaban en un medio fluvial en condiciones de flotación parcial o total. El tamaño y morfología

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sugieren que probablemente corresponden, al menos en algunos casos, con tortugas, lo que contribuye al conocimiento de las condiciones paleoambientales y paleofaunísticas del Triásico superior de Iberia durante el Carniense, un momento clave para la evolución de diferentes grupos de vertebrados continentales. En este trabajo presentamos un estudio comparativo de los tres yacimientos descritos hasta la fecha en Cortes de Pallás junto con un análisis de la interacción entre organismo productor, comportamiento y sustrato en la morfología resultante de las huellas generadas en condiciones subacuáticas.

Palabras clave Paleoicnología · Tortugas · Huellas de natación · Evento húmedo del Carniense · Triásico superior · Iberia

1 Introduction

The ichnological record from Spain had yielded, up to date, relatively few localities with vertebrate tracks regarded as Upper Triassic: (1) Cambil locality (Jaén province) with tracks that were assigned to the *Brachychirotherium* ichnogenus (Pérez-López, 1993; Reolid et al., 2020). (2) Carrascosa del Campo (Soria province), containing dinosaur tracks identified as *Eubrontes* and *Anchisauripus* (Pascual-Arribas & Latorre-Macarrón, 2000). (3) Three localities (Upper Triassic, Keuper facies) from Domeño, Quesa and Cortes de Pallás, Valencia province (Reolid et al., 2018) and a fourth also from Cortes de Pallás (Navarro & Moratalla, 2018).

Pérez-López (1993) regards the track-bearing stratigraphic section (Cambil) as part of the Keuper facies, but the outcrop conditions do not allow a more precise dating. The second locality (Carrascosa del Campo) is assigned to the Imón Fm, whose age would be Norian or even Rhaetian (Ortí, 2004). In the third case (Domeño, Quesa and Cortes de Pallás) the ichnites, mostly isolated, described in these outcrops have been interpreted as being produced by turtles in a semi-aquatic locomotion mode within the detritic sequences of the Manuel Formation (Reolid et al., 2018), of Carnian age. The latter, (Los Gallegos tracksite, also from the Manuel Formation—Keuper facies) constitutes a remarkable exception for its track number (over 65 prints) and preservation conditions (Navarro & Moratalla, 2018). These authors do not provide a precise producer identification, pointing to unknown reptiles of the chirotheroid group and therefore, related to archosauriform or archosaur crurotarsal reptiles.

Most of the aforementioned track-bearing localities (Quesa, Domeño and both Cortes de Pallás sites) are assigned to the Manuel Formation, or K2, one of the lithological units that made up the Keuper facies, as were defined by Ortí (1973, 1974). Therefore, the Manuel Formation stands out as the most remarkable stratigraphic unit regarding Upper Triassic vertebrate tracks in Eastern Iberia. This mostly detritic unit was deposited during the Carnian Pluvial Episode, a period of increased rainfall and humidity occurred during Late Triassic times (Ruffell et al., 2016). This period is thought to have lasted for several million years, and it is characterized by a number of geological and paleontological changes that are unique to this time (Benton et al., 2018; Benton & Wu, 2022; Dal Corso et al., 2020). This episode is well known for its effects on the distribution and diversity of plant and animal life. During this time,

there was a significant increase in the number of species found in tropical and subtropical regions, as well as an expansion of forests and wetlands (see for example, Dal Corso et al., 2020; Li et al., 2022; Peng et al., 2022). This period is also associated with the emergence of several important groups of animals, including early dinosaurs and the first modern crocodylians (Benton et al., 2018; Dal Corso et al., 2020; Ruffell et al., 2016). In eastern Iberia, it shows a transition environment, within an alternating high and low sinuosity sandy fluvial system connected to deltaic and restricted marine environments (Arche & López-Gómez, 2014; Barrenechea et al., 2018; Henares et al., 2014; López-Gómez et al., 2017; Navarro & Moratalla, 2018; Ortí et al., 2017; Reolid & Reolid, 2017; Reolid et al., 2018).

This apparent “Late Triassic opportunity window” for track preservation in Eastern Iberia may be related to these wetter climatic conditions and to the fact that, worldwide, most of the vertebrate tracksites seem to have been generated on sediments related to humid environments (lacustrine, fluvial, lagoon, etc.) (Lockley, 1991; Lockley & Hunt, 1995; Lockley & Meyer, 2000; Moratalla, 2008; Sarjeant, 1975; Thulborn, 1990). In addition, most of them contain locomotion tracks and trackways showing a preferential walking behavior (Lockley, 1991; Lockley & Meyer, 2000; Moratalla et al., 1997; Pérez-Lorente, 2015 and references therein). The walking behavior seems to be the most common pattern throughout the abundant and well-known dinosaur tracksites distributed worldwide, and it could also be extended to the pre-dinosaurian reptiles such as archosauriforms as well as several archosaurs (see for example Mujal et al., 2017). However, as was pointed out by Thomson and Droser (2015), the number of reported swimming vertebrate tracksites seems to have been increasing recently. This fact seems to be especially significant for the Early Triassic period, that shows an amazing number of “swimming tracksites” (see Fig. 1 in Thomson & Droser, 2015), more than any other period from the Phanerozoic times. This also seems to be the case in Eastern Iberia in Late Triassic times.

Tracks from the Manuel Formation are associated, for the most part, with a different animal behavior, and have been interpreted as produced by totally or partially buoyant animals during swimming or drifting, or even walking on the bottom, activities (Navarro & Moratalla, 2018; Reolid et al., 2018). In particular, Reolid et al., (2018) conducted a detailed analysis of a set of tracks from Cortes de Pallás and identified several distinct morphological features that are characteristic of terrestrial

turtles displacing in a semi-aquatic locomotion mode. Navarro and Moratalla (2018) described another tracksite locality from Cortes de Pallás containing ichnites that were produced by swimming, totally or partially buoyant archosauriform or archosaur crurotarsal reptiles in fluvial system with restricted marine influence.

The discovery of a new tracksite at the Cortes de Pallás area is an important finding for the study of the Spanish Triassic paleoichnological fossil record. This is due to the scarcity of Iberian Upper Triassic tracksites, which makes this discovery a significant addition to the existing fossil record. The new tracksite provides new data on the Late Triassic ichno-diversity. In addition to its significance for the study of the Triassic fossil record, the discovery of the new tracksite at Cortes de Pallás also provides an opportunity to study the relationship and interdependence among different factors in fluvial environments. These include the substrate on which the tracks were printed, the animals that left the tracks, and the behavior of these animals. The fact that this new tracksite is part of a high geographical concentration of tracksites from the same stratigraphical setting makes it possible to study the way these factors interplay in a more comprehensive and detailed way.

The aim of this paper is to describe and discuss the El Barranco outcrop, its vertebrate tracks, and to provide an interpretation of these findings in the context of the other described Upper Triassic localities at Cortes de Pallás. This includes the first tracksite described in Reolid et al., (2018), which is referred to in this paper as the El Ral tracksite, and a second tracksite described in Navarro and Moratalla (2018), known as the Los Gallegos tracksite (Fig. 1). By studying the El Barranco outcrop and its vertebrate tracks in the context of these other tracksites, it is possible to gain a better understanding of the animals and environments that existed in this region during the Late Triassic.

2 Geological setting and stratigraphy

The El Barranco creek is located in the municipality of Cortes de Pallás (Valencia province)—Eastern Spain—along a linear diapiric structure—the Cortes de Pallás diapir—in which the Keuper facies sedimentary record is widely exposed. This antiformal structure spreads in a SW–NE direction in the junction of the Iberian Range (to the north) and the Betic Cordillera (to the south), in the northernmost limit of the Valencian Domain (Navarro-Carrasco & Meléndez-Hevia, 2020) (Fig. 1).

The Keuper facies in the area are mainly composed of gypsum, lutites, sandstones and minor carbonates deposited in continental to shallow marine conditions. Its features suggest the presence of a mainly mixed evaporitic-detritic marine, transitional and fluvial environments (López-Gómez et al., 2017). The strata are highly affected

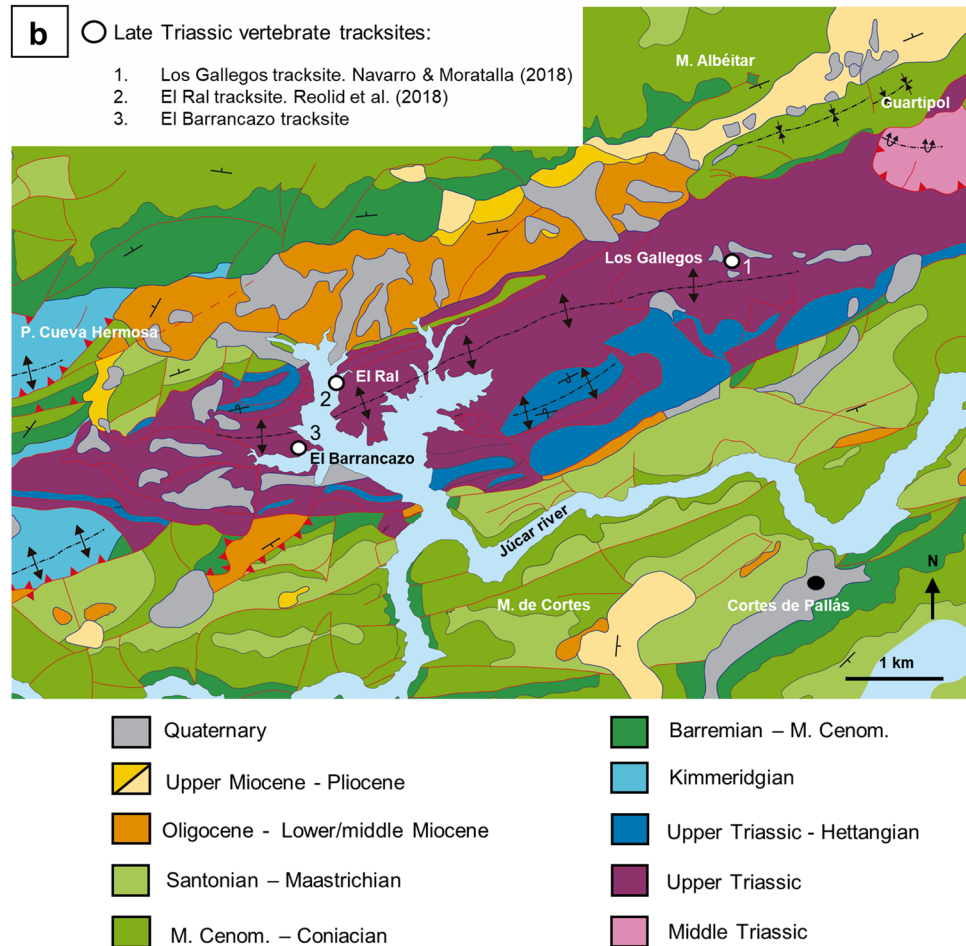
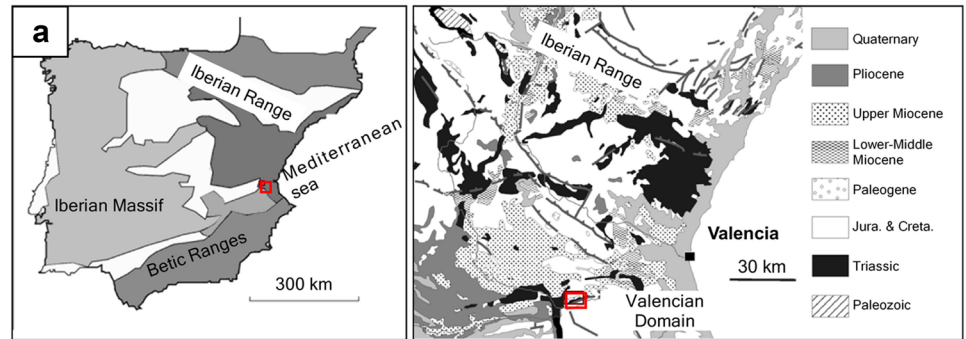
by diapirism and tectonics, being frequently verticalized or even overturned. The contacts between the five lithostratigraphic units that constitute this facies may show mechanization, with some carbonate blocks visible along the diapir axis (Lendínez & Dávila, 1980; Navarro-Carrasco & Meléndez-Hevia, 2020).

Creeks and ravines cut through the less competent units (mostly lutites), modelling a badland-like landscape. One of these watercourses eroding the diapir is El Barranco creek (Figs. 2 and 3), where this new vertebrate tracksite is located. The track-bearing layers (Fig. 4) are located in a mixed siliciclastic-evaporitic sequence near the base of the Manuel Formation or K2 (Ortí, 1974) (Fig. 2 shows the stratigraphic log for the El Barranco site). In this area this mostly detrital sedimentary package lies conformably on the Jarafuel Formation or K1 (Ortí, 1974) and could be correlated, based on its stratigraphic position overlaying the uppermost K1 gypsum beds, with the lower unit (Unit 1) out of the three ones in which Arche et al., (2002) subdivided this formation in the southeast of the Iberian Peninsula, later named K-2.1 in Arche and López-Gómez (2014) and in López-Gómez et al., (2017). The contact between both formations is well exposed on the tracksite area, sitting at the top of a bed of laminated, black-grey gypsum. The Manuel Formation is a heterolithic lithostratigraphic unit composed by lutites, sandstones and minor interbedded carbonates and marls. It shows a colorful appearance in the study area, displaying a variety of red, green, gray and yellow colors. Its systematic analysis is hampered by tectonics and diapirism, which heavily disrupt these materials. Diverse palynological studies consistently assign the Manuel Formation to a Carnian age, firstly proposed by Solé de Porta and Ortí (1982), and later corroborated by Pérez-Hidalgo and José (1990), Arnal et al., (2002), Arche et al., (2002), and Arche and López-Gómez (2014). Later this unit was considered to be Julian in age by Barrenechea et al., (2018).

At the studied location, the El Barranco creek has incised the Keuper materials closely following the beds' strike. Besides, the Cortes de Pallás reservoir has partially flooded the creek. As a result, the outcrop forms a SW-NE oriented peninsula that projects into the Júcar river along the northern bank of the creek (Figs. 1 and 3a). This bank consists of a steep cliff cut on the K2 beds, which are heavily distorted, laying almost vertical with the K1 strata thrusting outwards the K2 at some places. The outcrop beds' strike and dip are 245, 81S. The track-bearing boulders lay at the base of this bluff, on a beach-like slope that is normally underwater. At this point, the beds are dissected almost perpendicular to strike, exposing the base of the Manuel Formation and its contact with the underlying Jarafuel Formation (Fig. 3).

Previous interpretations of the Manuel Formation proposed that it was deposited in fluvial environments that show, at some levels, a variable degree of marine influence (Arche & López-Gómez, 2014; Arche et al., 2002;

Fig. 1 Geographical and geological setting of the El Barrancazo area. **a** El Barrancazo tracksite location in Iberia. **b** Geological map of the El Barrancazo creek area and nearby Upper Triassic tracksites, modified from Navarro-Carrasco and Meléndez-Hevia (2020)



Ortí, 1987). Ortí (1987) suggested that, in the central Valencian area, the transition from the Jarafuel Formation to the overlying Manuel Formation (that include the new El Barrancazo locality) shows features characteristic of interdistributary bay deposition. Arche et al., (2002) concluded that the base of the Manuel Formation (unit 1 or K-2.1) can be interpreted as a fluvial braided system, with sparse associated crevasse splay deposits and probably some marine influence in the eastern-most limit of the studied area.

3 Materials and methods

Fieldwork at El Barrancazo tracksite was performed during a series of several days of abnormally low water level, which exposed the track-bearing slabs and boulders and made the outcrop fully accessible. Tracks were photographed with a mobile digital device camera and measured, providing material for detailed analysis. Relevant specimens were labeled with a code (EB-LX-Y.Z) where EB stands for El Barrancazo, X corresponds with

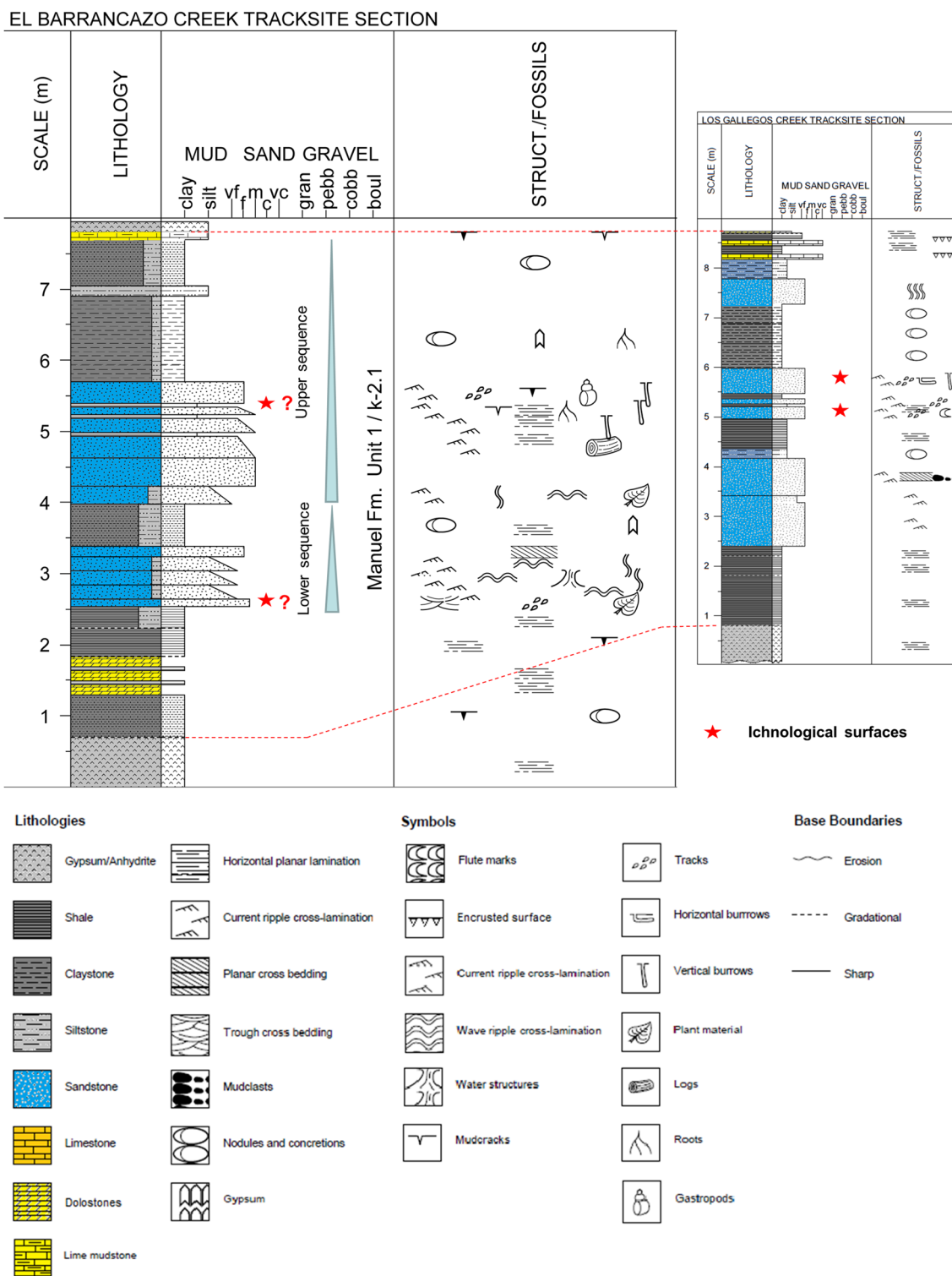


Fig. 2 El Barrancazo section stratigraphic log. The vertebrate tracks provenance is putatively assigned to two distinct beds, designed as levels 1 and 2. Two fining-upward sequences can be identified. The studied section can be correlated with the unit 1 in Arche et al.,

(2002), later named unit K-2.1 in Arche and López-Gómez (2014) and in López-Gómez et al., (2017). A correlation with the stratigraphic log of the Los Gallegos tracksite, as shown in Navarro and Moratalla (2018), is provided

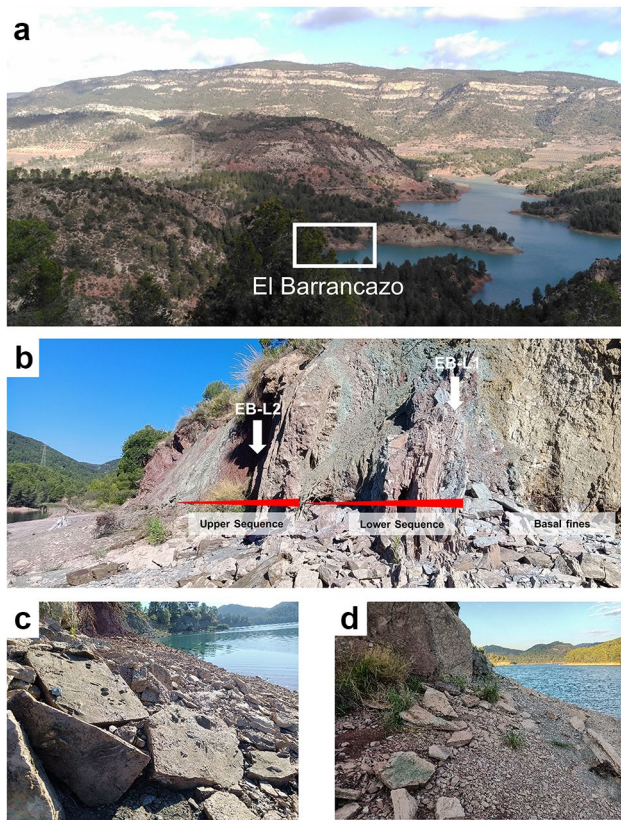


Fig. 3 Locality general views. **a** Keuper facies cropping out in El Barrancazo creek. **b** General view of the locality showing the two beds the track-bearing slabs and boulders come from. The outcrop beds' strike and dip are 245, 81S. **c** View of a set of track-bearing slabs from level 1. **d** View of a set of track-bearing boulders from level 2, laying at the base of the beds they come from

the track-bearing horizon, Y corresponds with an specific track-bearing slab (group of slabs in some cases) and Z represents the track number (the correspondence between tracks and codes is provided in annotated sketches and is available for download—online resource 1—). The prints pictures were processed to get digital sketches. The measurements considered useful for analysis and comparison are presented in Tables 1 and 2, along with indications regarding the presence of relevant morphological traits. All slabs and blocks were left in situ.

The stratigraphic layers were also carefully logged and both sedimentological and stratigraphical analyses have been carried out.

Finally, a comparative analysis has been performed in order to identify similarities and differences among the three aforementioned Cortes de Pallás tracksites, considering morphological measurements and relevant features, compiled in Table 3.

Photographs were taken of the most complete and best-preserved slabs from both ichnological levels in order to

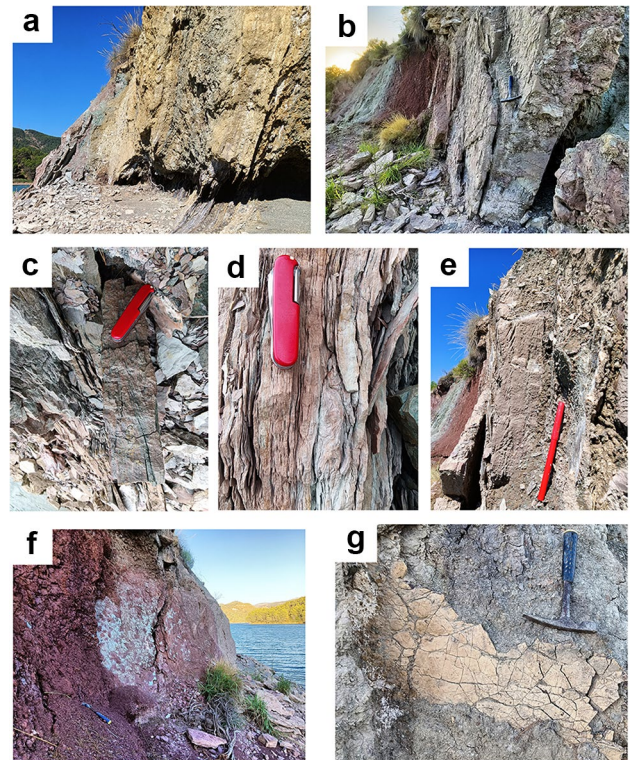


Fig. 4 Sedimentary structures from El Barrancazo locality. Stratigraphic up is to the left, unless otherwise stated. **a** Cross-section of the base of the outcrop. Laminated gypsum and interbedded lutites and dolostones overlaid by very fine to medium-grained silty-sandstones. **b** Cross-section of the upper part of the outcrop. Interbedded silt and fine to medium-grained sandstones overlaid by laminated and nodular lutites. **c** Trough cross-bedding in sandstones with muddy-silty drapes. **d** Cross-section of heterolithic (flaser) beds showing fining-upward cycles of sandstones with ripple and wave cross-lamination and water escape structures. **e** Planar cross-bedding in sandstones. **f** Parallel laminated sandstones displaying convoluted laminae. Stratigraphic up is to the right. **g** Rubefacted marls and gypsum on the top of the studied section

generate digital 3-D models for future reference using photogrammetry techniques and the software MESHROOM v2021.1.0.

4 Sedimentology

4.1 Description

The section that contains the ichnological surfaces consists of a fine-grained set of lutites and minor evaporites and carbonates which contains two intercalated sandstone packages, and is organized in two major fining-upward depositional sequences (Figs. 2 and 3).

The succession begins with a gypsum layer displaying algal lamination (Fig. 4a) overlaid by dark colored (black, gray) nodular lutites that contain some sparse rubefacted silts

Table 1 Measurements and morphological features of tracks in El Barrancazo level 1 (EB-L1)

Track code	Level	Measurements			Number of digital marks	Morphological features				Digit edge
		Length (cm)	Width (cm)	Relief (mm)		Posterior/lateral overhangs	Striations	Digit reflectures	Deeper contact	
EB-L1-1.1	1	5	6	10	3	Posterior			X	Acum. Blunt
EB-L1-1.2	1	21	8	15	3					
EB-L1-1.3	1	10	10	12	3	Posterior			X	
EB-L1-1.4	1	9	3.5	5	2					
EB-L1-1.5	1	6	4.5	20	2					
EB-L1-1.6	1	18	2.5	8	1			X		Blunt
EB-L1-1.7	1	4	4	8	3	Posterior				Acum. Blunt
EB-L1-1.8	1	9	7	20	2	Posterior				
EB-L1-1.9	1	6	8	10	3					
EB-L1-1.10	1	6	3.5	8	4					Acum. Blunt
EB-L1-1.11	1	5	9	20	3				X	
EB-L1-2.1	1	6	6	20	2	Posterior				Blunt
EB-L1-2.2	1	5.5	6.5	18	2	Posterior			X	Acum.
EB-L1-2.3	1	5	5	12	4	Posterior			X	Acum.
EB-L1-2.4	1	5	8	10	4	Posterior			X	Acum.
EB-L1-2.5	1	10	5	10	1	Lateral			X?	Acum.
EB-L1-2.6	1	11	4	12	2				X	Blunt
EB-L1-2.7	1	11	2.5	20	1					Blunt
EB-L1-2.8	1	12	17	50	-					
EB-L1-3.1	1	7	4.5	15	2	Posterior				Blunt
EB-L1-3.2	1	12	6	10	1					Blunt
EB-L1-3.3	1	7	13	20	2					Blunt
EB-L1-4.1	1	18	15	20	4				X	Blunt
EB-L1-4.2	1	14	6.5	6	4	Posterior + Lateral			X	Acum.
EB-L1-4.3	1	8	3	15	2					Blunt
EB-L1-5.1	1	16	8	25	2					Blunt
EB-L1-5.2	1	6	6.5	18	2	Posterior		X	X	Blunt
EB-L1-6.1	1	21	2	8	1					Blunt

The main characters observable in single tracks (lateral and posterior overhangs, striations, digit reflectures and evidence of deep contact) are registered (see text for details)

Table 2 Measurements and morphological features of tracks in El Barrancazo level 2 (EB-L2)

Track code	Level	Measurements			Number of digital marks	Morphological features								
		Length (cm)	Width (cm)	Relief (mm)		Posterior/lateral overhangs	Striations	Digit reflectures	Deeper contact	Digit edge				
EB-L2-7.1	2	4.5	2	10	1	Posterior								
EB-L2-7.2	2	12.5	11.5	25	3	Lateral		X		X		X		Acum.
EB-L2-7.3	2	8	11	18	3									Blunt
EB-L2-7.4	2	8	9.5	14	3	Posterior + Lateral								Blunt
EB-L2-7.5	2	5	2	12	1	Posterior							X	Blunt
EB-L2-7.6	2	5	7.5	25	4									Blunt
EB-L2-8.1	2	5	7	15	4						X			
EB-L2-8.2	2	13	17	35	2	Posterior + Lateral		X		X		X		Acum.
EB-L2-8.3	2	10	9	15	1	Lateral		X		X				Acum.
EB-L2-8.4	2	3.5	2	18	1									Acum.?
EB-L2-8.5	2	5	6	18	-									
EB-L2-9.1	2	7	5	15	2	Posterior + Lateral		X						Acum.
EB-L2-9.2	2	5	9	18	3									Blunt
EB-L2-9.3	2	5	6	10	2									Blunt
EB-L2-9.4	2	7	8	25	-									
EB-L2-10.1	2	13.5	3	10	2	Lateral								Acum.
EB-L2-10.2	2	10.5	2	12	1	Lateral								Acum.
EB-L2-10.3	2	9	6	10	2									Blunt
EB-L2-10.4	2	11	7	30	4				X			X		Blunt
EB-L2-11.1	2	7	5.5	12	2				X					Blunt
EB-L2-12.1	2	18	5	15	3	Lateral			X		X			Acum.
EB-L2-12.2	2			45 ¹		Posterior + Lateral			X			X		Blunt
EB-L2-12.3	2	2	6	11	2									
EB-L2-12.4	2	6.5	5.5	12	2	Posterior + Lateral		X				X		Blunt
EB-L2-13.1	2	7	5.5	10	2	Lateral		X						Acum.
EB-L2-14.1	2	7	10	20	2	Posterior + Lateral		X			X			Acum.

The main features observable in single tracks (lateral and posterior overhangs, striations, digit reflectures and evidence of deep contact) are registered (see text for details)

(1) Max. relief from the slab's prints

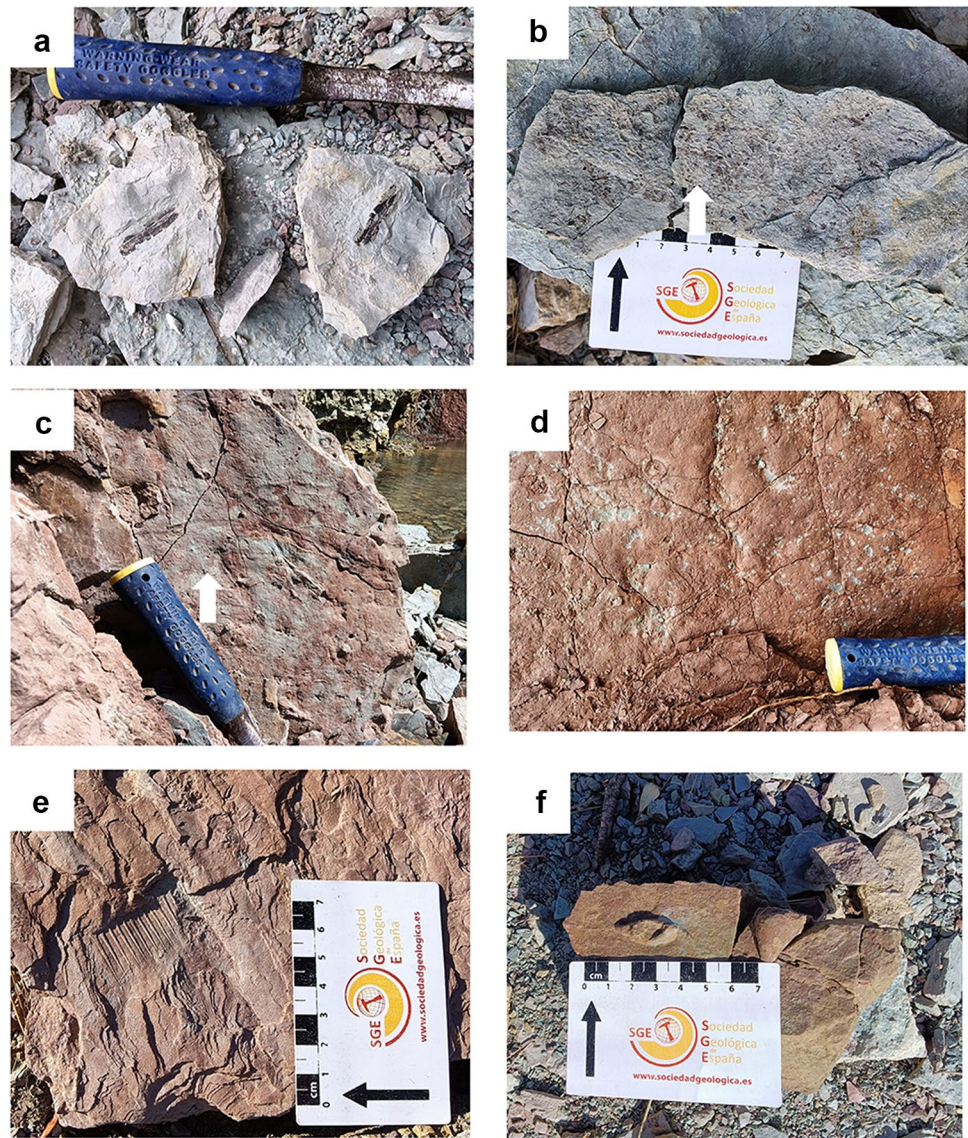
Table 3 Comparative analysis of measurements and morphological features from the three Late Triassic tracksites in Cortes de Pallás: El Barancazo (this work), El Ral (Reolid et al., 2018) and Los Gallegos (Navarro & Moratalla, 2018)

Proportion of prints (%)	LG	EB-L1	EB-L2	ER
1 digit	8.5	18.5	21.7	0.0
2 digits	32.2	40.7	43.5	26.3
3 digits	32.2	22.2	21.7	68.4
4 digits	25.4	18.5	13.0	5.3
5 digits	1.7	0.0	0.0	0.0
Length (cm)	LG	EB-L1	EB-L2	ER
1 digit	8.5	14.4	6.7	0.0
2 digits	9.8	8.2	7.7	8.0
3 digits	12.5	8.5	10.3	9.0
4 digits	12.0	9.6	7.0	18.1
5 digits	7.5			
Width (cm)	LG	EB-L1	EB-L2	ER
1 digit	7.0	3.6	3.4	0.0
2 digits	8.9	6.0	7.0	8.5
3 digits	10.6	7.5	9.2	11.2
4 digits	11.7	7.6	7.2	8.1
5 digits	14.0			
Depth (mm)	LG	EB-L1	EB-L2	ER
1 digit	14.8	11.2	14.4	
2 digits	19.5	17.1	14.5	20.0
3 digits	21.2	12.5	18.0	21.1
4 digits	17.7	11.2	23.3	
5 digits	18.0			
Proportion of prints (%)	LG	EB-L1	EB-L2	
Posterior overhangs	27.1	37.0	8.7	
Lateral overhangs	0.0	3.7	26.1	
Post. + lat. overhangs	0.0	3.7	21.7	
Long. striations	62.7	7.4	43.5	
Digit reflectures	16.9	37.0	26.1	
Kick off scours	3.3	0.0	0.0	
Deeper contact	3.2	3.6	19.2	
Digit blunt edges		55.6	43.5	
Digit acum. edges		25.9	43.5	

and ferruginous concretions. Next follows an alternation of dark shales with interbedded gray, centrimetric, marly dolostone layers. This fine-grained basal set ends with a bed of green (red at the top), silty lutites. On top of this fine grained basal package and in sharp contact comes a bed of fining-upward, fine to medium, moderately sorted, well-cemented white quartz sandstones that display trough cross-bedding with fine-grained, dark drapes intercalated within the laminae sets (Fig. 4c). These drapes are made of submillimeter-scale carbon particles, mica flakes and carbonaceous plant debris (Fig. 5a, b). The base of this bed shows some scarce elongated features interpreted as faint sole-marks. This is the

bed which, based on lithology, is supposed to contain the first ichnological surface (EB-L1). Next come a pack of very well sorted, very fine to fine, red/green sandstones structured in fining-up cycles that are topped by a millimetre-scale layer of clayish silts. These sandstones contain submillimeter-scale carbon particles, mica flakes and show current and oscillation ripple cross-lamination, flaser lamination and water-escape structures (Fig. 4d). Bioturbation is scarce, consisting in vertical (*skolithos* isp.?) and horizontal burrows of about 1–2 mm in diameter (Fig. 5c). No other epifaunal traces have been observed, apart from some thin superficial scratch marks interpreted as invertebrate locomotion traces.

Fig. 5 Fossils and trace fossils in El Barrancazo tracksite. **a** and **b** Carbonaceous plant debris. **c** Sandstones displaying minor bioturbation with scarce vertical and horizontal burrows. **d** Rhizocretions on the top of a sandstone bed, a probable paleosol from the upper part of the section. **e** Impression of an equisetites trunk on rippled sandstones. **f** Undetermined fossil gastropod from the level 2 ichnological surface. All of the pictures show the top of the bed



On top of these cyclic package lays a bed of well-cemented, fine-grained sandstones with scarce mica flakes and carbonaceous plant debris displaying ripple lamination and planar cross-bedding (Fig. 4e). Neither desiccation cracks nor other evidences of subaerial exposure have been observed. Overlaying this first coarse-grained package there is a set of laminated, silty mudstones displaying a nodular texture at the base. Their color is pale green/gray and contain some interbedded millimeter-scale gypsum lenses, constituting the top of the lower sequence.

The upper sequence of the section begins with a coarse-grained package that consists of a succession of red sandstones with planar and current ripple lamination organized in fining-upward cycles with interbedded lutites (Fig. 4b). Sandstone's grain size varies from very fine to medium. The lower beds display mud-silt drapes, mica flakes and carbonaceous plant debris. The upper beds show trunk

impressions and gastropods (Fig. 5e, f). Bioturbation is scarce, consisting in vertical and horizontal burrows and, at the uppermost bed, rhizocretions (Fig. 5d). This top bed is supposed to contain the second ichnological surface at its base (EB-L2). Some bed surfaces within this package display iron-rich crusts and concretions, faint desiccation cracks and reduced spots (Fig. 4f).

The uppermost part of the section consists of a new fine-grained succession. It begins with a pack of red, nodulous claystones with rhizocretions and thin gypsum lenses (Fig. 4f) followed by a bed of green silts and new package of green, nodulous, silty mudstone. The section is topped by a fining-up sequence made up of interbedded iron-rich carbonate (marly dolostones) crusts and, finally, a layer of grey gypsum (Fig. 4g). This upper evaporitic layer probably represents the final stage of this sequence.

Small-scale, erosional sedimentary structures (sole marks), especially those that would allow to estimate the paleocurrent direction (crescent marks, flute casts, etc.) are almost totally absent. Therefore, it has not been possible to estimate paleocurrents direction for the track-bearing surfaces.

4.2 Interpretation

The El Barranco stratigraphic record begins with evaporitic levels at the base (laminated gypsum) and dark, laminated lutites that are overlaid by siliciclastics that constitute the main sedimentary body. The studied section contains two fining-upward depositional sequences that show fluvial conditions on their lower part and a restricted shallow marine influence in their upper part (Figs. 2 and 3). A detailed study of lithofacies is beyond the scope of this work. However, based on the sedimentological information gathered, a broad interpretation can be put forward.

The set of sedimentary features observed in the base of the lower sequence is coherent with a fluvio-tidal transition zone interpretation. Among them: unidirectional trough cross-stratification and ripple cross-lamination, abundant carbonaceous debris, massive bedding, heterolithic lamination, mud drapes and water-scape structures (see for example Dalrymple & Choi, 2007 and Shchepetkina et al., 2019). In particular, the presence of mud drapes formed by the minute carbonaceous debris seems to be evidence of an environment with variable energetic conditions, maybe due to tidal or even seasonal influence (Shchepetkina et al., 2019). The scarcity of trace fossils and the low bioturbation degree observed at the basal beds, with just some isolated horizontal and vertical burrows close to the top of the lower section, seems to be compatible with a brackish-water environment model (Buatois et al., 2005 and references therein), characterized by a relatively low ichnodiversity and scarce epifaunal traces.

On the other hand, the upper sequence can be interpreted as a fluvial floodplain where the finer overbank deposits (mudstones and siltstones) alternate with sandstone beds with planar to ripple lamination deposited during more energetic episodes, like crevasse splays (Miall, 1996).

The presence of carbonates and the gypsum lenses observed in the uppermost part of both sequences point to an occasional marine influence with the sporadic occurrence of evaporitic conditions (López-Gómez et al., 2017).

In this context, the evolution recorded in these sediments could be interpreted as the evolution from a fluvio-tidal transition zone to a fluvial floodplain in a coastal setting: the basal finer-grained beds (dark shales, gray mudstones and dolostones), deposited under low energetic conditions, could be interpreted as bay or abandoned channel deposits (Stewart, 1983). The cross-bedded and rippled sandstone

beds would have probably been laid out by periodic higher energy episodes like crevasse splays that deposited the sandstones inter-bedded with the overbank fines, thus showing that current activity was not continuous, but occurred as several distinct events. These crevasse episodes are especially notable in the upper sequence. The presence of iron-rich crusts and concretions, nodular textures in mudstones, reduced spots and mottling and desiccation cracks correspond in our interpretation with a mostly well-drained floodplain (Bown & Kraus, 1987; Kraus, 1999; Turner, 1980). The rhizocretions observed in the upper sequence register the colonization of the floodplain by plants.

The proposed interpretation seems to fit with the evolution from intertidal, semi-arid mudflats to distal ephemeral rivers debouching into a marginal marine, low-energy coastal zone described in Arche and López-Gómez (2014), in accordance with the progressive establishment of fluvial environments during the Carnian Pluvial Episode (Arche & López-Gómez, 2014; Berra, 2012; Ortí et al., 2017).

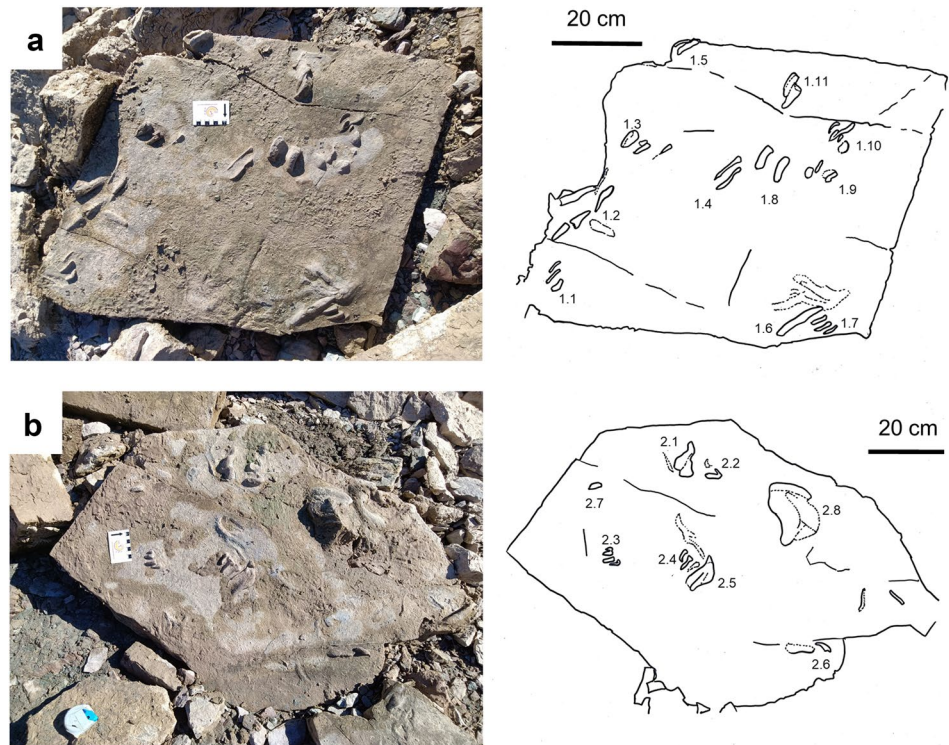
The base and the top of the El Barranco section can be correlated with their equivalent at the Los Gallegos tracksite (Fig. 2). In a general sense, the El Barranco materials are coarser-grained than the ones in Los Gallegos, display a lesser degree of marine influence and probably represent their equivalents in a more proximal setting. It has not been possible to locate in the Manuel Formation the position of the track-bearing beds from El Ral tracksite described in Reolid et al., (2018) since no detailed sedimentological analysis is provided by the authors and the site is not accessible.

5 Tracksite description

The El Barranco track-bearing beds are exposed along the creek's left bank (Fig. 3a). Tracksite coordinates are 39° 15' 14" N/0° 59' 21" W. Because of the beds' dip, only the top of the strata is widely exposed, and so no track can be observed in situ. All of the identified and studied specimens are contained in blocks and slabs detached from the outcropping beds. These blocks are trapezoidal in shape. Their width and length range from 5–10 cm in the smaller ones, to 50–100 cm in the larger ones (Fig. 3c, d). Their thickness is more constant, around 15–20 cm. Track number per block varies widely, between 1 and 11. Based on the block's spatial distribution and lithology, two stratigraphic levels (named EB-L1 and EB-L2) have been identified as their probable source (Fig. 3b, c, d; Tables 1 and 2).

A total number of 6 blocks/slabs have been assigned to the level 1 (Table 1). Slabs numbered 1–4 are especially relevant, being the only ones large enough to allow for a potential trackway identification (Fig. 6). 8 blocks/sets have been assigned to the level 2 (Table 2). In this case, blocks

Fig. 6 Sketches of the most complete track-bearing slabs from level 1. **a** Slab EB-L1-1. **b** Slab EB-L1-2. Tracks EB-L1-1.1 to EB-L1-1.5 constitute the only clear alignment observable on the site



are smaller, each containing a lower number of tracks than those in level 1.

The ichnological impressions are made up of natural positive reliefs (natural casts) on the bottom of each of the layers. These hypo-reliefs are generally quite well preserved, clearly visible and present a notorious volume that allows an acceptable characterization of the observed elements.

All the tracks or fragments of prints found are isolated, that is to say, without being part of a clear locomotion trackway. However, in some of the blocks clear alignments of tracks can be observed (Fig. 6a) suggesting a certain direction of movement for the trackmaker. It should also be noted that some of the blocks present a high density of ichnites forming truly spectacular paleoichnological assemblages. Nonetheless, its appearance on detached and isolated blocks prevents, in most cases, the recognition of trackways. Therefore, the systematic analysis is mainly based on individual morphological traits and measurements.

5.1 Level 1 (EB-L1)

The tracks on level 1 are formed by clear impressions, with well-marked and conspicuous reliefs and, in general, with a clearly recognizable morphology. Some isolated impressions present well-marked toes with a clear, continuous outline and a relatively high relief. Most of the prints are

only formed by digital impressions. Although the heel region has not been preserved, some of the tracks display evidence of a deeper contact of the autopodium with the substrate (i.e., specimen EB-L1-2.8, Fig. 6).

The slab #1, 0.5 × 0.5 m in size, shows a series of tracks with digital impressions with a subparallel arrangement (Fig. 6a). The most noticeable feature of this slab probably is the set of tracks labeled EB-L1-1.1 to EB-L1-1.5, which form a clear alignment that suggests a direction of movement from EB-L1-1.5 to EB-L1-1.1. It also seems clear that no trackways are recognizable. Furthermore, none of the tracks is complete: rather, they consist of subparallel digital impressions with no evidence of net support on the substrate. Something similar can be said regarding slab #2, although in this case the EB-L1-2.8 track could be an exception (Fig. 6b).

Other isolated tracks from level 1 displaying a good preservation of digital elements are shown in Fig. 7, consisting mostly of isolated impressions of subparallel arrangement. In some cases, clear digital reflectures (Fig. 7b), overhang structures (Fig. 7c), very long backwards elongation of the digital impression (Fig. 7d) and longitudinal striations (Fig. 7e) are very well preserved. The track labelled EB-L1-4.2 (Fig. 7d) is very interesting: the toes are relatively long and slender, well separated from each other, slightly curved -especially the two central toes- and quite acuminate at their distal termination.

Fig. 7 Morphological features of tracks in level 1. **a** Four parallel digital marks in specimen EB-L1-2.3. Note also the digital single reflecture. **b** Single reflecture, specimen EB-L1-2.2. **c** Posterior overhangs, specimen EB-1.8. **d** Variable track length, specimen EB-L1-4.2 Note the posterior overhangs in the central digital marks. **e** Lateral overhangs, specimen EB-L1-2.4. **f** Longitudinal striations on digit marks, specimen EB-L1-5.2. Note the lateral overhangs and the single reflecture. All of the pictures show the base of the bed



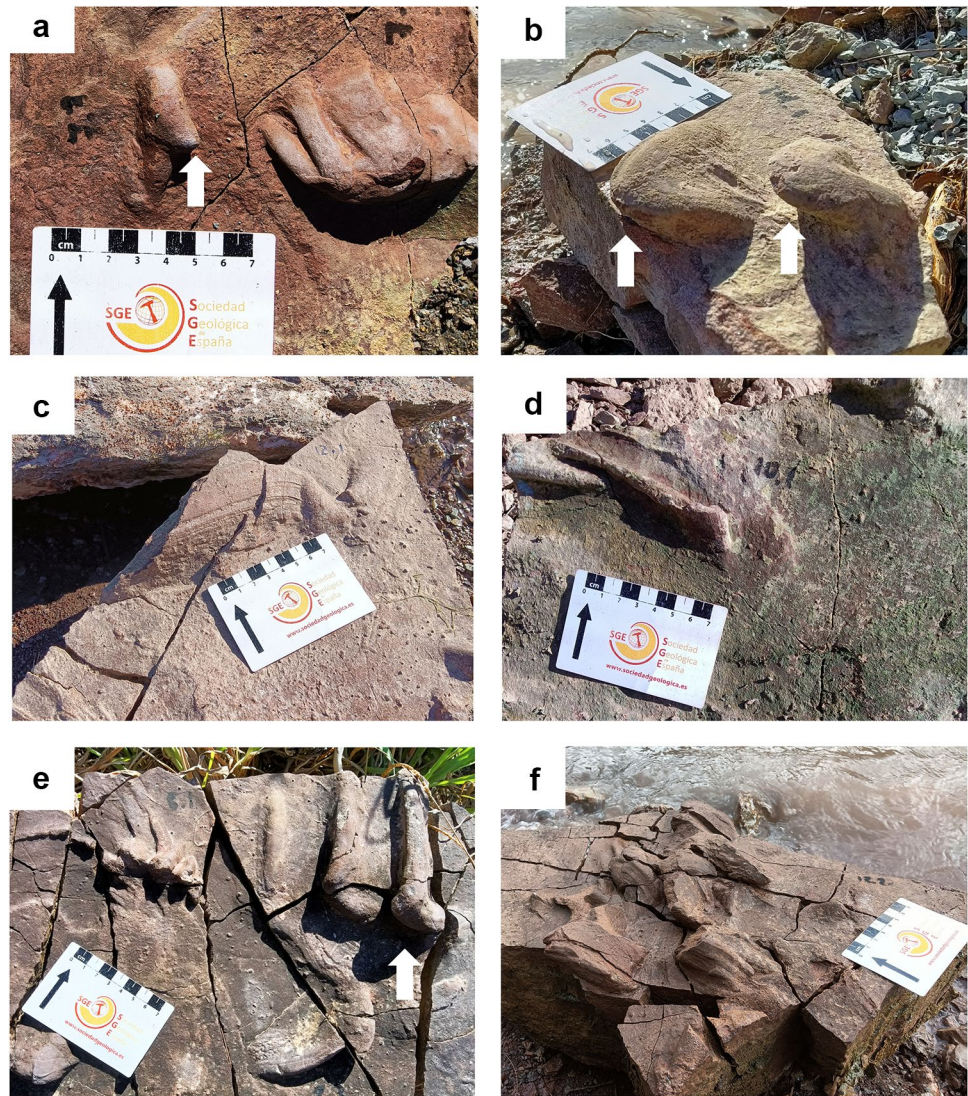
5.2 Level 2 (EB-L2)

Some of the most interesting specimens of the level 2 are a group of tracks distributed in several isolated blocks (Fig. 8). These prints are also mostly formed by parallel, linear, quite elongated digital impressions. They display overhangs (Fig. 8a, b), clear longitudinal striations (Fig. 8b, c) or Z-shaped structures (Fig. 8e). Although there are ichnites displaying substrate scuff marks (Fig. 8e), others are more compact and have even preserved a more proximal zone resulting in a more net, complete and closed outline (Fig. 8a, b, f).

Although EB-L2 traces display a wide range of variation, both in size and shape -being probably partial impressions- most of the tracks show two to three digital marks and they clearly display a subparallel digital arrangement.

Digits are significantly spaced, leaving a gap between them comparable with the width of the digital marks (Figs. 7 and 8b, e). Although some of the digits show acuminate distal ends (Fig. 6a), most of them show a blunt morphology (Figs. 7 and 8). The shape and parallel disposition of the preserved digits suggest that they are mostly the I, II, III and IV ones, and in consequence, it is remarkable the absence of the digit V throughout the El Barranco prints. The absence of the heel region, of the digit V and of manus prints prevents us from easily identifying even if a track belongs to the right or to the left autopodium. Most of the preserved digits show a rather straight morphology but, in some cases, they are slightly curved (Figs. 7b, c, f and 8b, e). A high number of digits show longitudinal striations and several alteration prints such as scrape marks (Figs. 7f and 8c). No body nor tail impressions have been found.

Fig. 8 Morphological features in level 2. **a** Posterior overhangs (arrow), specimen EB-L2-7.3, and complex track displaying digital marks and evidence of a deeper contact with the substrate, specimen EB-L2-7.6. **b** Lateral overhangs (arrows), specimen EB-L2-14.1. **c** Longitudinal striations on digit marks, specimen EB-L2-12.1. Note the extraordinary width of the digital mark, probably due to its low angle to the bed surface. **d** Variable track length, specimen EB-L2-10.1. **e** Single reflectures, specimen EB-L2-8.2. **f** Slab showing extensive trampling of a set of superposing tracks, specimen EB-L2-12.2. All of the pictures show the base of the bed



5.3 General considerations

Track size is highly variable, the total width of the prints depending mainly on the number of preserved digits, being these about 1–2 cm wide. Therefore, the average width of the footprints that have 4 preserved digits, is about 7 cm. In addition to this, a relatively high variability in terms of track length has been observed. The largest track from El Barranco is located on level 1 and it shows only one digital mark: this track has a length of about 21 cm and is 2 cm wide. On the other hand, the smallest track is made up of three digits, showing a length of about 4 cm (Table 1).

When comparing the morphological features observed in the footmarks from the level 1 and 2 of the El Barranco tracksite, we can point out the following main differences (Table 3):

- Close to 50% of the tracks from EB-L2 display lateral overhangs (or combined lateral + posterior overhangs). This proportion is significantly lower at EB-L1, less than 8%. On the contrary, tracks at EB-L1 show a greater proportion of posterior overhangs when compared to the EB-L2 ones (37% vs. 8.7%).
- Tracks at EB-L2 display longitudinal striations in a greater proportion than the ones at EB-L1 (43.5% vs. 7.4%).
- Tracks with morphological traits suggesting a greater contact of the autopodium with the sediment are more common at EB-L2 than at EB-L1 (19.2% vs. 3.6%).

In both cases, the tracks show a good preservation of fine details, probably due to the presence of a relatively firm substrate (a firmground). The lesser proportion of tracks displaying longitudinal striations at EB-L1 could be explained

by erosion, given the more energetic conditions associated with the deposition of the trough-crossbedded sandstone bed that contains the tracks.

Regarding geometrical measurements, tracks at EB-L1 and EB-L2 show similar width and length distribution. The more outstanding difference between both levels is the far greater depth of 3-to-4 digit tracks at level 2 (Table 3). A more detailed analysis show that these deeper tracks also display morphological features associated with a greater load of the autopodium on the bottom (Tables 1 and 2).

Despite the high degree of trampling visible at the site, no clear trackways nor the presence of potential manus prints have been recognized. This fact prevents an easy identification of the tracks, as comparison between manus and pes tracks is one of the significant features for the classification and identification of the known Triassic reptile fossil tracks. This is also the case of trackway pattern main measurements (stride, pace length, trackway width, relative location of manus/pes prints), which are also very important for track identification and comparison.

6 Discussion

6.1 Ichnological analysis

The morphological traits observed in the tracks and compiled in Tables 1 and 2 can be compared with a set of diagnostic criteria for traces produced by total or partially buoyant vertebrates, suggesting that most of them were probably produced by reptiles during drifting or swimming activities.

These type of swimming scenarios have been recognized and described since Peabody (1948, 1956) and Lammers (1964). These authors identified a series of diagnostic criteria later systematized by McAllister (1989) and McCallister and Kirby (1998), discussed in Thomsom and Lovelace (2014) and compiled in Navarro and Moratalla (2018):

(a) Reflecture of digits and Z-traces, produced when the tracemaker's foot changes directions during footmark production resulting in swipe marks which are curved or v-shaped in the case of single reflectures; (b) posterior overhangs, caused during the swim stroke by the toe tips of the autopodium on the sediment; (c) kick-off scours; (d) impressions of distal digit ends during paddling activities; (e) longitudinal striations along the digits, produced by the scales or the claws as they scratch the substrate parallel to propulsion; (f) absence of regular locomotion patterns capable of producing clear trackways; (g) absence of manus prints; (h) highly variable trace lengths; (i) expected sedimentary features; (j) paleoenvironmental interpretation compatible with subaqueous track production.

These criteria are intended to be used as a whole, with traits from different categories being taken together as complementary lines of evidence. The more diagnostic features to determine swim tracks are those related to buoyancy such as posterior overhangs, striations, kick-off scours, digit reflectures, variable trace length, and unexpected or incomplete trackway configurations (McAllister & Kirby, 1998). Some of the mentioned swim track features can be identified in the El Barranco track-bearing layers, specially the most relevant features for a swimming locomotion mode interpretation that can be observed in single tracks, which are: longitudinal striations and posterior overhangs and digit reflectures (no kick-off scours have been identified at El Barranco).

An underwater track production mode is also supported by the general morphology of the traces (subparallel toes with no connection between them or very elongated projection marks posteriorly directed). In addition, except for some isolated potential cases, it is very remarkable the absence of footprints displaying a complete morphology and the absence of locomotion trackways showing a clear pattern. In fact, almost all the footprints are isolated (without forming part of a trackway) and only one alignment suggesting a sense of progression can be highlighted, as already mentioned, in level EB-L1 (Fig. 6a).

In addition to these characters, an additional feature has been recognized in El Barranco traces: lateral overhangs (Figs. 7e and 8b, f). These are lateral, outward projections that create an overhang in an oblique direction to the digit trace axis. This results in curved, asymmetrical digit prints with exteriorly orientated tips. Lateral overhangs were described in the El Ral site traces by Reolid et al., (2018), who interpreted them as the result of the position of the limb girdled inside turtles' shell and the arrangement of the openings between the plastron and the carapace. This allow for limbs retraction and reduce the range of limb movements in both the horizontal and vertical planes. These authors interpreted the El Ral tracks as being produced by terrestrial turtles while swimming near the bottom.

The interpretation of the environmental context and the sedimentological structures observed in the beds containing the track-bearing level EB-L1 are also compatible with the subaqueous production of the tracks. In the case of the level EB-L2, the sandstone bed directly overlays one of the mudstone beds that punctuate the crevasse splay deposits. However, in this floodplain environment, a subaerial production of the tracks on a wet substrate cannot be fully ruled out, at least for some of the EB-L2 traces. In this latter case, the substrate was probably not fully desiccated at the time of production of these tracks, since the fine-grained bed representing the floodplain surface at the moment of the prints production seems to display faint mudcracks (Fig. 5d). Specimen EB-L2-12.2 (Fig. 8f) constitutes one of these unclear

cases: several traces overlap, with faint single digit traces, posterior and lateral overhangs and the second deepest track in both level 1 and 2, all evidences pointing out to lesser, if any, buoyancy conditions.

The incomplete preservation of hand and foot prints, as well as the lack of a trackway, make it difficult to confidently assign an ichnotaxonomic classification to most of the prints from the El Barranco outcrop. The subaqueous production of these tracks does not allow a consistent morphological comparison: their complete outline is missing, and their size, observable digital features and track arrangement suggest great differences with respect to the well-known track record of the Triassic, represented by the chiroteroid tracks such as *Chirotherium*, *Isochirotherium* or *Brachychirotherium*, as the main ones (Díaz-Martínez et al., 2015); Melchor & de Valais, 2006; Valdiserri & Tichy, 2008). These are characterized -among other factors- by pentadactyl ichnites with the V toe directed laterally and the toes I-IV directed forward with a mostly divergent arrangement. These are prints mainly denoting a clear support on a relatively firm substrate, quite different from the El Barranco interpreted paleoenvironment.

Besides, the study of turtle tracks and the classification of their fossilized footprints (ichnotaxonomy) has been challenging due to the significant differences between the tracks made by swimming and walking turtles, and those made by other aquatic and semi-aquatic animals (see Avanzini et al., 2005; Costa da Silva et al., 2009; Moratalla et al., 1995; Xing et al., 2014). Avanzini et al., (2005) only recognized two ichnogenera of turtle tracks as valid: *Chelonipus* and *Emydhipus*. *Chelonipus* is characterized by a digitigrade to semiplantigrade hand with four or three claws, and a foot with four connected digits that are joined by a fleshy arched structure (see Xing et al., 2014). *Emydhipus* consists of hand prints with four parallel elongated claw marks and a plantigrade footprint with four digits bearing thin claws and a short, rounded sole. *Emydhipus* has been found in Upper Jurassic and Lower Cretaceous deposits in Spain (e.g. Avanzini et al., 2005; Fuentes Vidarte et al., 2003; Moratalla & Hernán, 2009) and Morocco (Belvedere et al., 2013), as well as in Lower Cretaceous rocks in Xinjiang, China (Xing et al., 2014). *Chelonipus* has been reported from the Lower Middle Triassic (Anisian) of Germany (Rühle & Lilienstern, 1939), and from the Upper Lower Triassic (Spathian) of Wyoming and Utah (Lichtig et al., 2018). Some individual tetradactyl tracks from El Barranco exhibit nearly parallel digits and a slight median arch comparable to those seen in *Chelonipus*: for instance EB-L1-2.3, EB-L1-2.5 at level 1 (Fig. 7a, e) or EB-L2-8.1 (Fig. 8e) at level 2.

Additionally, one of the morphotypes for tracks caused by vertebrate swimming activity is the ichnogenus *Caracichnos* (Whyte & Romano, 2001). The ichnogenus *Caracichnos* refers to thin, elongated marks that result from the

rubbing of the toe distal tips on the substrate during vertebrate swimming activity. This classification is based on the genetic makeup of the scrape marks rather than the morphology of the trackmaker. However, this ichnogenus, based on production mode rather than on anatomical morphology does not suit well the purpose of trackmaker identification. Indeed, for this, a morphological rather than a genetic approach is needed. This concept can be applied to the El Barranco tracksite, where some of the tracks, particularly those from EB-L1, can be identified as belonging to the ichnogenus *Caracichnos*, such as, for example EB-L1-1.1, EB-L1-1.4, EB-L1-1.7, and EB-L1-1.8 (Fig. 6a).

Taking into consideration the features and ichnological analysis presented above, we propose that at least some of the tracks from the El Barranco EB-L1 are best explained as traces produced by totally or partially buoyant turtles. However, tracks at EB-L2 are more heterogeneous: some were probably produced under subaqueous conditions in a similar scenario described for the EB-L1. However, some of them seem to have been produced by animals floating with lesser buoyancy or even walking in shallower water, which resulted in a greater autopodium load on the bottom.

6.2 Comparative analysis of the El Barranco, El Ral and Los Gallegos prints

When comparing the El Barranco tracks with the others from the two sites described from Cortes de Pallás, namely Los Gallegos and El Ral, the following observations can be pointed out:

- Individual traces display the same set of morphological traits associated to a subaqueous production. However, there are two remarkable differences: (1) lateral overhangs (unique or combined with posterior ones) were not reported from Los Gallegos, being exclusive from El Barranco and El Ral. (2) Prints showing a deeper contact of the autopodium with the substrate are present in a greater proportion at the EB-L2 than at Los Gallegos and at EB-L1 (Table 3).
- Morphological measurements comparison shows that the prints from Los Gallegos are, in most cases, larger than the ones from the other tracksites. The EB-L1 tracks display a lesser depth than the ones from EB-L2 and the other localities.
- In a broad sense, imprints on EB-L2 seem to display a higher level of load on the substrate than those on EB-L1.
- Most of the Los Gallegos digit imprints display blunt edges. At El Barranco EB-L2 a similar proportion of acuminate and blunt digital edges has been observed, whereas at El Barranco EB-L1 prints showing digital blunt edges are clearly predominant.

- Individual digit prints in Los Gallegos traces are closely spaced, almost overlapping. Traces from El Barranco and El Ral are somewhat different, displaying for the most part a wider digit separation.
- Prints from El Ral display a number of digits ranging between 2 and 4, with a clear dominance of 3-digit prints (over 68%) in clear contrast with the other tracksites, all of which contain a significant number of 1-digit traces (over 18% at El Barranco).

As a result, from the aforementioned comparative analysis we conclude that:

- Print features from El Barranco closely match those from El Ral, being this especially true for the El Barranco level 2.
- There are some clear differences among, on the one hand, Los Gallegos and El Barranco EB-L1 and, on the other hand, El Ral and El Barranco EB-L2: lesser proportion of prints displaying evidences of a deeper contact of the autopodium on the bottom; greater number of prints displaying lateral overhangs; digit imprint shape and, finally, print size.

These differences could be related to the production environment, trackmaker and to animal behavior. In particular, the track suite from El Barranco EB-L2 matches the expected pattern of turtles in a semiaquatic locomotion mode, swimming partially buoyed or maybe walking on the bottom in shallow waters (regarding body size), as interpreted by Reolid et al (2018) for El Ral tracksite. This is compatible with the paleoenvironmental interpretation: a crevasse splay episode that temporarily developed on a floodplain. On the other hand, the El Barranco EB-L1 producers could also be terrestrial turtles, as proposed for El Barranco EB-L2. In this case, the observed differential features in some tracks point out to a swimming displacement mode in more buoyant conditions, or even to different producers in some cases. The lesser contact of the limbs on the bottom maybe due to a deeper water level in relation to the producer's body size (i.e. the result of paddling activity) as proposed by Navarro and Moratalla (2018) for the reptile prints from Los Gallegos tracksite. Again, this interpretation fits well the paleoenvironmental analysis.

The ichnological evidence of vertebrates displacing in a swimming locomotion mode is very diverse, being the result of the interaction of environmental, morphological, and behavioral factors. Among others: autopodia morphology, limb length, water depth, bottom topology, buoyancy, and swimming behavior (i.e., buoyancy vs. punting, see for example Farlow et al., 2018). This results in the generation of a diverse ichnological record, even for the same producer. Therefore, a proper assessment of all of these factors is key to understand the animal behavior and highlights the importance

of a thorough paleoenvironmental interpretation, since the substrate conditions are the only factors that are independent from the trackmaker. In this sense, a fluvial environment like the one present in eastern Iberia during the Carnian Pluvial Episode offers an opportunity to study the interplay of all the aforementioned factors. In particular, the Cortes de Pallás area, with the richest ichnological record from Carnian times in Iberia, stands out as a key locality for further future analysis.

7 Conclusions

In the last few years, the Upper Triassic of Cortes de Pallás (Eastern Iberia) is providing interesting findings of reptile tracks. El Barranco site described in this work is the latest of them, after El Ral and Los Gallegos. In all of them, both the subaqueous activity of archosauriform reptiles (Los Gallegos) and turtles (El Ral and very likely El Barranco) have been described, providing very relevant information, from the paleoichnological point of view, regarding the aquatic behavior of different types of reptiles from the Carnian stage.

The morphological features of the tracks from El Barranco, combined with a detailed paleoenvironmental analysis, support a subaqueous production mode and constitute a paradigmatic case for the study of the ichnofossils associated with this kind of activity.

Although the genetic origin of the El Barranco prints does not allow an adequate morphological comparison with the two known turtle ichnogenera (*Chelonipus* and *Emydhipus*), some of the El Barranco tracks show sub-parallel digits as well as a slight medial arch comparable to those observed in the *Chelonipus* ichnogenus. However, since trackways are lacking, a more precise identification cannot be made at this time.

The great concentration of swimming reptiles tracksites in Cortes de Pallás, all from diverse but closely related fluvial sedimentological settings, provides an opportunity for the comparative study of the interplay of producer organism, animal behavior and substrate in track morphology.

Finally, the study of El Barranco tracksite adds very relevant information to better understand the evolution of this type of fauna during the Carnian Pluvial Episode, a peculiar period that must have significantly influenced the paleoecological and paleoclimatic conditions under which several continental vertebrate communities faced a very singular moment in their evolutionary and adaptive process.

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Data availability All raw data is provided in the article. As a consequence, we regard this statement as non applicable.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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