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Trace fossils of floating reptiles from the Carnian in the Tabular Cover (S Spain)

Trazas fósiles de reptiles en flotación del Carniense de la Cobertera Tabular (Sur de España)

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ABSTRACT

Small trace fossils are recorded in the top and the bottom of a thin sandstone bed located in the upper part of the K1 unit (lower Carnian, Upper Triassic), in the Tabular Cover. In the top surface, two trace fossils have been identified: a tridactyl digitigrade elongated scratch mark with preserved triangular claws (20 mm long and 19 mm wide), with two lateral elongated (30 mm) and curved marks are located back to the margins of the tridactyl footprint, and a longitudinal furrow (185 mm long and 3 mm wide). In the bottom surface there are two autopodium impressions preserved as convex hyporeliefs, counter moulds (45 mm long, 26 mm wide, and 18 mm long, 14 mm wide). They are tridactyl, elongated scratch marks, located very close and forming an angle of 48º. Trace fossils are interpreted as produced on the bottom by small tetrapods when floating in a low energy shallow environment. In the top surface correspond to the right hindlimb and the tail. In the bottom surface the scratch marks are more elongated and may be related to pes and manus. The potential authors are uncertain. This is a new example of swimming trace fossil for the Carnian deposits of the southern and eastern Iberia.

Keywords: Sedimentology; Ichnology; 3D models; Upper Triassic.

RESUMEN

Las superficies de techo y muro de un nivel delgado de arenisca de la parte superior de la unidad K1 (Carniense inferior, Triásico Superior) de la Cobertera Tabular, presentan pequeñas trazas fósiles de vertebrados. En la superficie de techo se han identificado dos trazas fósiles: una marca alargada de arañazo tridáctilo, digitígrado que preserva la impronta de las garras (20 mm de largo y 19 mm de ancho), con dos marcas laterales curvadas y alargadas (30 mm) que continúan por detrás de la huella tridáctila, y un surco longitudinal (185 mm de largo y 3 mm de ancho). En la superficie de muro aparecen dos huellas preservadas como contramoldes (45 mm de largo, 26 mm de ancho, y 18 mm de largo, 14 mm de ancho). Son huellas tridáctilas, constituidas por marcas elongadas de arañazos, localizadas muy cerca entre sí, formando un ángulo de 48º. Las trazas fósiles fueron producidas en el fondo de un medio acuático muy poco profundo y de poca energía, por pequeños tetrápodos que estaban flotando o caminando sobre el fondo. Las huellas de la superficie de techo corresponden a la extremidad trasera derecha y a la cola de un organismo desconocido. Las huellas de la superficie de muro son marcas elongadas de arañazos

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en el fondo posiblemente relacionadas con el pie y la mano. Este es un nuevo ejemplo de huellas de un tetrápodo en flotación o natación en los materiales del Carniense del Sureste de Iberia.

Palabras clave: Sedimentología; Ichnología; Modelos 3D; Triásico Superior.

Introduction

Trace fossils of aquatic and semi-aquatic locomotion of vertebrates have been reported from the shallow marine deposits of the Middle Triassic Muschelkalk facies (Berrocal *et al*., 2022), from the coastal facies of the Middle Triassic of the Tabular Cover (Reolid & Reolid, 2017; Reolid *et al*., 2020), and from the Upper Triassic fluvial sandstones of the Manuel Formation or K2 unit (Reolid et al., 2018; Navarro & Moratalla, 2023). The Upper Triassic (Carnian) records show the relation of Triassic reptiles with aquatic environments in a time in which, global environmental changes drove a substantial reduction of species diversity and the subsequent major radiation of organisms, mainly reptiles (see Dal Corso *et al*., 2020). This is the Carnian Pluvial Episode, represented in the Iberian plate by the Manuel Formation (Arche & López-Gómez, 2014). In this short note, we report a new example of semi-aquatic locomotion of a vertebrate from the lower Carnian of the Tabular Cover, an area where the record of fossil vertebrates is very scarce.

Materials and methods

The trace fossils are located in a thin (3-4 cm thick) sandstone bed of the Carnian of the Tabular Cover (Terrinches section) that present well-preserved ripples at the top and dense bioturbations of invertebrates in the bottom. A total of 4 slabs were studied. Vertebrate trace fossils are located in a slab (47 cm length and 30 cm width). The sandstone slabs have been surveyed by means of close range photogrammetry techniques (Luhman et al., 2020) in order to generate both 2D (orthoimages) and 2.5D (digital elevation models –DEM-) products, as well as a global 3D model of both sides of the slab. The camera used for photogrammetric survey was a SONY ILCE-5000 with APS-C sensor equipped with a SONY Macro FE 50 mm F2,8 lens. Images were processed with Agisoft Metashape Pro 2.0.1 (AGISOFT, 2024). The photogrammetric processing steps to obtain the different products are outlined in Reolid et al. (2020). A total of 244 images were necessary to cover both sides of the slab at an average camera-object distance of 40 cm with a resolution of 0.04 mm/pix. The photogrammetric network was scaled by some taped distances measured near the slab. The final scaled 3D model was assembled and edited in CloudCompare v2 (CloudCompare, 2025). The DEM and orthoimages were processed with QGIS 3.34.11 (QGIS, 2025) to generate hillshaded models, contours and height maps which have allowed to highlight and enhance the trace fossils. The complete 3D model is available for visualization in the Museo Paleontológico Virtual of the Universidad de Jaén (PALEOV-UJA) at https://alquivir.ujaen.es/museo/ripple-marks-y-huellas/.

Geological setting

The Terrinches section was originally studied by Fernández et al. (1976) in La Hoz ravine (coords. 38º35’44’’N, 2º49’8’’W) at 2.4 km southeast from Terrinches village (Fig. 1). The section is constituted by a 120 m thick sequence of sandstones, siltstones, and locally conglomerates and dolostones (Fernández, 1977). The Tabular Cover constitutes the horizontal redbeds deposited along the southeastern edge of the Iberian Variscan Massif (Fig. 1). In southern Spain, the Triassic red beds of the Tabular Cover correspond mainly to the Upper Triassic Keuper facies, with the units K1, K2, K3, K4 and K5 that may be correlated with other formations defined in the Triassic of External Zones of Betic Cordillera and from eastern Iberia such as Jarafuel Formation (or K1), Manuel Formation (or K2), Cofrentes Formation (K3), Quesa Formation (K4) and Ayora Formation (K5) (Arche & López-Gómez, 2014). In the Terrinches section, the K1 and K2 units are well represented. The K1 unit is constituted by 50 m of an alternation of sandstones and siltstones with local record of calcarenite beds. The base is composed of a conglomerate on a discordance surface with the Palaeozoic metamorphic rocks of the Iberian Massif (Fig. 1C). Most of the sandstone beds present small-scale cross bedding and surfaces with ripple marks. The studied sandstone bed is located in the uppermost part of the K1 unit in a surface with interference ripple marks. The K2 unit is constituted by a 60 m thick interval with three thick sandstone bars separated by siltstone intervals (Fig. 1C). The sandstone bars show characteristic megaripple cross-bedding and lateral changes of thickness. Over the K2 unit, there are siltstones with increasing content of gypsum to the top of the section, surely corresponding to K3 unit in the lower part (first 25 m) and K4 and K5 units in the layers with gypsum (upper 30 m).

The K1 unit has been dated with palynological assemblages as lower Carnian (Cordevolian) in neighbour sections in Alcaraz and Reolid localities (Arche & López-Gómez, 2014) and in other areas (Besems, 1981; De Torres, 1990).

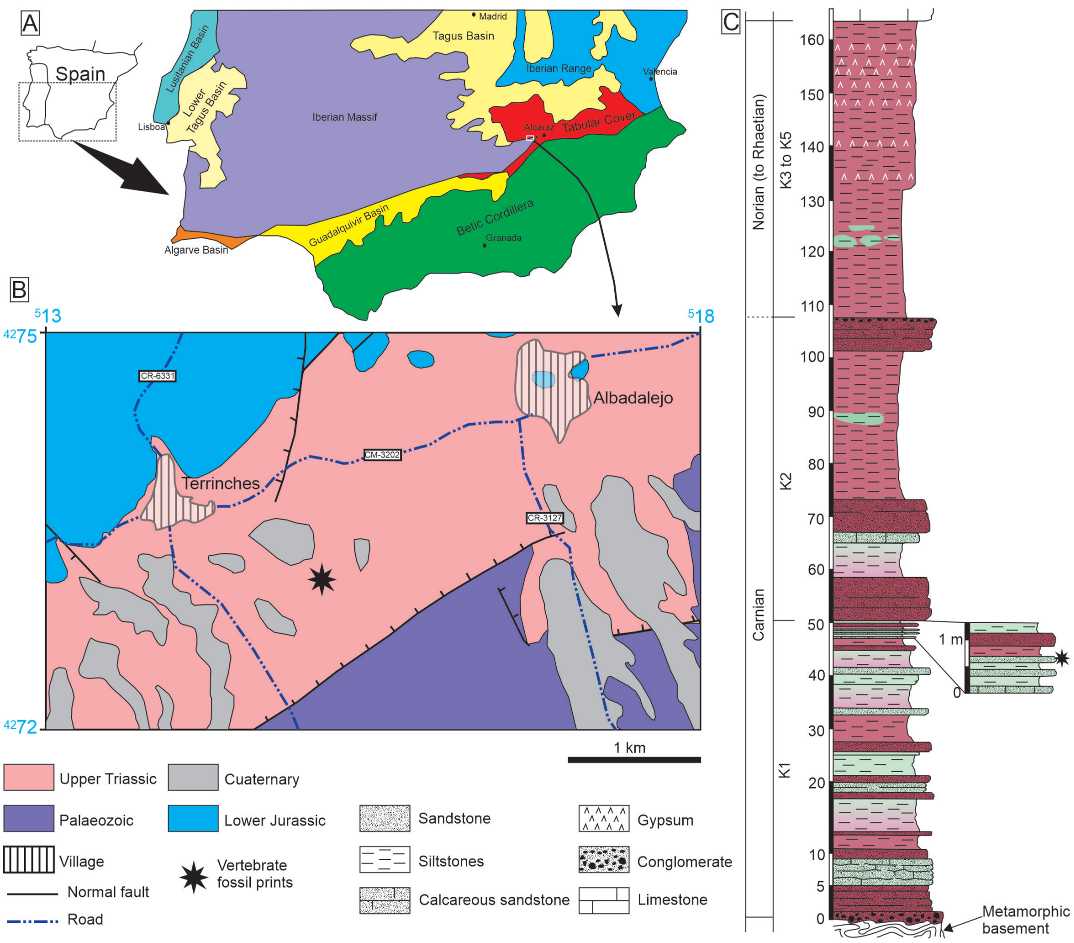

Figure 1.— Geological setting. A. Simplified geological map of the southern part of the Iberian Peninsula with the main structural units (the studied area is indicated with a white rectangle. B. Geological sketch of the area of the Terrinches and Albadalejo (Ciudad Real province) with a star indicating the location of the studied vertebrate trace fossils. C. The Terrinches section with location (star) of the stratigraphic position of the vertebrate trace fossils.

Results

The studied sandstone bed is characterized by the presence of two different sets of asymmetrical ripple marks overlapped on the top surface (Fig. 2A and B). The main ripples present straight crest that laterally change to irregular with bifurcated crests, with the maximum height around 10 mm, and wavelength of 36 mm. The secondary ripple marks are straight and well developed in the trough between the main ripple crests.

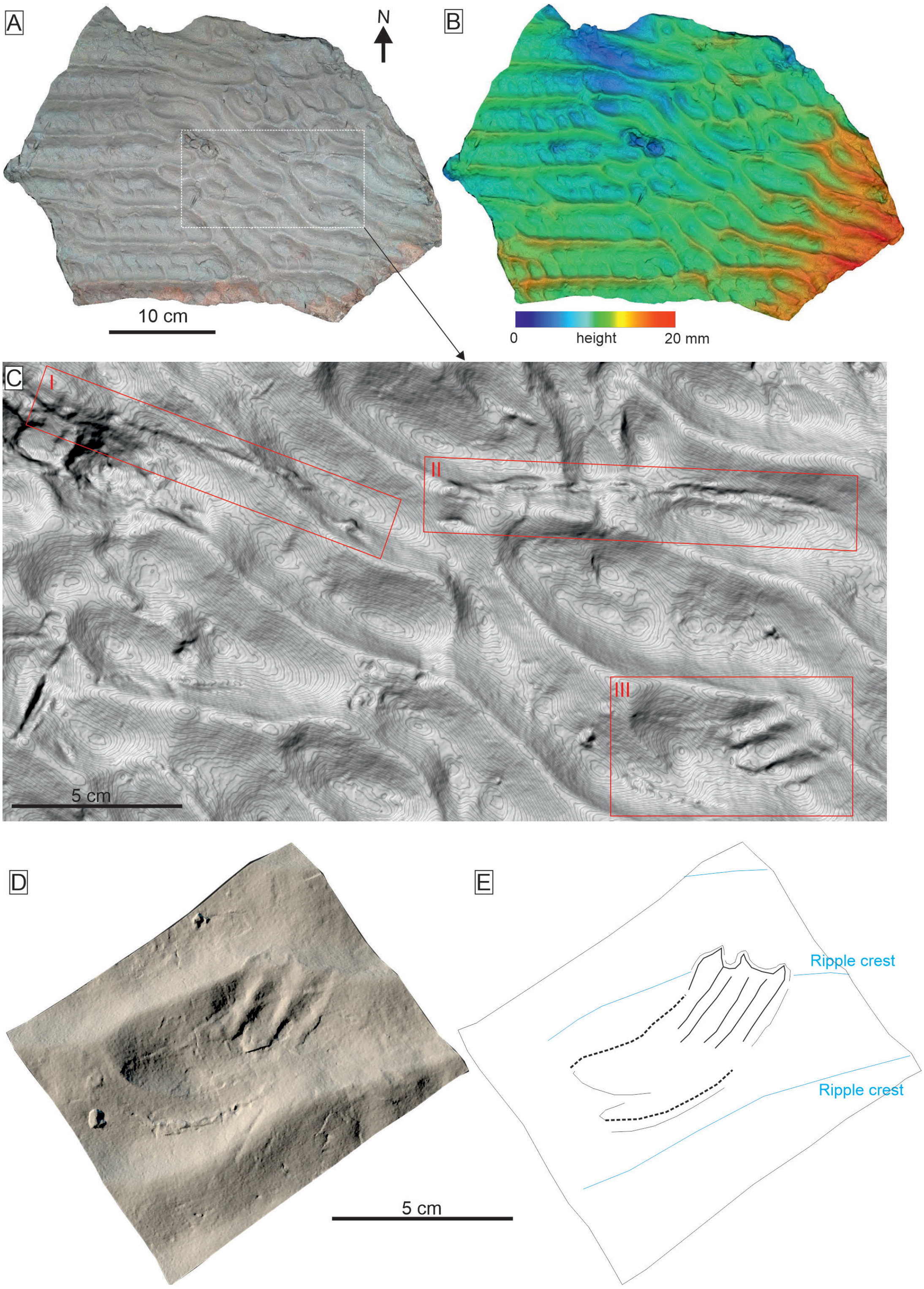

Figure 2.— Top surface of the sandstone bed with vertebrate trace fossils. A. Orthoimage of the sandstone slab (upper side) showing interference ripples and vertebrate trace fossils. Original resolution of the orthoimage is 0.2 mm/pix. B. Digital elevation model (DEM; original resolution of 0.1 mm). The DEM surface has been enhanced by overlaying a derived hillshaded model and contour levels. C. Hillshade map, derived from the DEM, showing details of the slab (white rectangle in 2A): a sinuous trail of unknown origin (I and II), and a tridactyl footprint (III). D and E: Section of the 3D model (this model shows a solid texture, instead a photorealistic one, in order to highlight subtle differences in the modelled surface) at the III in Figure 2C, and sketch of the tridactyl footprint with two lateral elongated and curved marks are located back to the margins of the tridactyl footprint.

These secondary ripples present lower height (< 5 mm) and wavelength (10-13 mm) than the main ripples. The angle between the palaeocurrents is around 80º, with the dominant palaeocurrent pointing to the north and secondarily to the east. The lower surface of the sandstone bed is densely bioturbated by small invertebrate trace fossils (see 3D model in https://alquivir.ujaen.es/museo/ripple-marks-y-huellas/).

The studied vertebrate trace fossils of the top are constituted by two different elements:

1. A tridactyl digitigrade elongated scratch mark with preserved triangular claws. The edge of the footprint presents a thin rim of sediment formed by mud extrusion. The width of the footprint is 19 mm (21 mm including the sediment rim) and the length is 20 mm (21 mm including the sediment rim). In addition, two lateral elongated and curved marks are located back to the margins of the tridactyl print. The distance between both elongated marks is 19 mm. The total length of the mark including finger print and back elongated marks is 49 mm (see a high-resolution 3D model of this trace in https://alquivir.ujaen.es/museo/detalle-huella/).
2. A longitudinal furrow 185 mm long and 3 mm wide, with an irregular morphology because of the interaction with undulated surface of the ripples. The longitudinal furrow is located 44 mm far from the tridactyl footprint. Considering the position of the claws in the tridactyl footprint, the longitudinal furrow is located to the left. The longitudinal furrow is interrupted in two segments of 89 and 96 mm respectively that form an angle of approximately 150º.

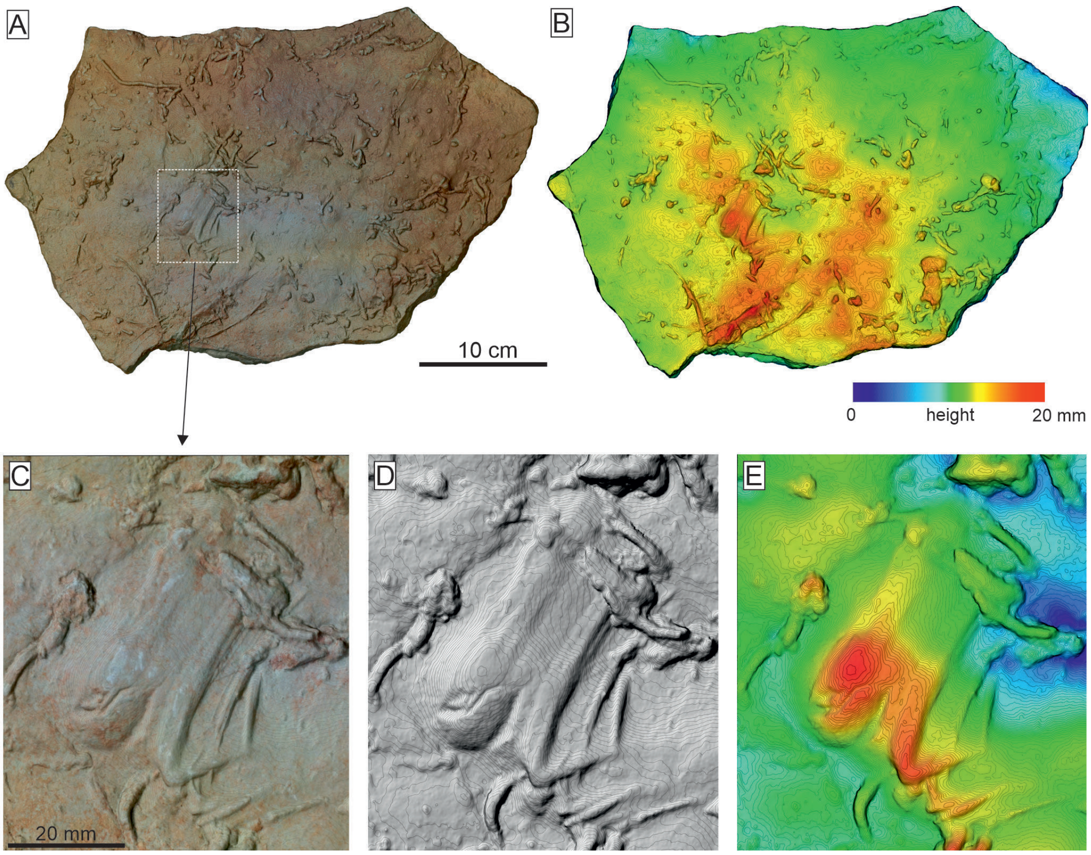

Figure 3.— Lower surface of the sandstone bed densely bioturbated by invertebrate trace fossils. A. Orthoimage of the sandstone slab (lower side) showing invertebrate and vertebrate trace fossils. Original resolution of the orthoimage is 0.2 mm/pix. B. DEM with original resolution of 0.1 mm. The DEM surface has been enhanced by overlaying a derived hillshaded model and contour levels. C. Sector of the orthoimage (white rectangle in 3A) showing the vertebrate trace fossil preserved as convex hyporelief structure. D. Section of the hillshade map, derived from the DEM, showing details of the vertebrate trace fossil (white rectangle in 3A). E. Sector of the DEM (white rectangle in 3A). The height colour scale of the general lower slab DEM (Fig. 3B) has been rescaled for this section in order to enhance the micro relief of the trace.

The studied vertebrate trace fossils of the bottom surface are constituted by autopodium impressions preserved as convex hyporeliefs, counter moulds (Fig. 3). The largest one is 45 mm long and 26 mm wide and corresponds to an elongated scratch mark with three main parallel, straight groove casts. The smallest trace fossil is 18 mm long and 14 mm wide and is constituted by three elongated and parallel scratch marks. Both tridactyl trace fossils are located very close and forming an angle of 48º. The largest one is deeper than the smallest one (Fig. 3).

Interpretation

The morphology of these traces suggests the tridactyl digitigrade elongated scratch mark were produced by the autopodium of a tetrapod while swimming near the bottom or while walking in the bottom with partial floating. Scratch mark of the top surface in this context as opposite to a well-preserved morphology of footprint confirms this was produced when the weight of the organism was partially or totally supported by the water (floating) (e.g., Milner *et al*., 2006; Farlow *et al*., 2018; Reolid *et al*., 2018; Xing *et al*., 2023). The elongated furrow was produced by the tail when dragged on the undulated bottom. The size of the animal was surely small considering the size of the fossil footprint and the distance between the footprint and the tail trace (44 mm), that is meaning the limbs-span was lower than 10 cm. Considering the position of the claws respect to the tail print, the fossil footprint corresponds to the right hindlimb. The curvature of the back elongated mark, concave respect to the tail print, confirm this was the right limb. Reptiles use tail movements to generate the propulsive stroke in swimming in the case of aquatic reptiles or use tail and hindlimbs in the case of non-aquatic reptiles.

In the case of the scratch marks of the bottom surface they were also related to bottom-walking or swimming small tetrapod. According to the size and depth within the sediment, it is possible interpret that the largest one corresponds to pes and the smaller one to manus. However, the distance (together) and angle (48º) is not congruent with a trackway where the angle is lower (see McCrea *et al*., 2004). Therefore, these scratch marks were produced in different moments, and not necessarily for the same organism.

The potential author or authors of these trace fossils are undetermined, including small archosaurs, small-size (including juvenile) crocodylomorphs, sphenodonts, lizards, and turtles among others. Some of these groups appeared in the Middle Triassic and diversified during the Carnian (see Dal Corso *et al*., 2020). These traces are similar to that actually produced by crocodiles when walking on the bottom, partially floating (Farlow et al., 2018).

The upper part of the K1 unit has been interpreted as deposited in a marginal marine environment to distal fluvial plain where seasonal lacustrine environments could be developed (see review in Arche & López-Gómez, 2014). The interference of ripples, indicating different currents, could be also related to a tidal environment. In any case, this was a very shallow and low energy environment. Fernández (1977) found fish teeth in this part of the Terrinches section, but there are not taxonomic indications that allow interpreting marine or fresh-water environments for the top of K1 unit in this area.

Conclusions

The small trace fossils of the Terrinches section, Tabular Cover, are located in the top of the K1 unit and corresponds to the lower Carnian. Trace fossils were produced on the bottom by a small tetrapod, probably a reptile, when floating in a relatively shallow water column in a low energy environment. The trace fossils recorded on the top surface correspond to a tridactyl digitigrade elongated scratch mark produced by the autopodium of the right hindlimb, and an elongated furrow produced by the tail when dragged on the bottom. The trace fossils recorded in the bottom surface are also small tridactyl scratch marks related to swimming or bottom-walking behaviour. The potential tracemaker is an indeterminate tetrapod at present. These new specimens increase the number of occurrences of swimming trace fossils recorded in the Carnian deposits of the southern and eastern Iberia.

DATA AVAILABILITY

The complete 3D model is available for visualization in the Museo Paleontológico Virtual of the Universidad de Jaén (PALEOV-UJA) at https://alquivir.ujaen.es/museo/ripple-marks-y-huellas/, with license of use © 2025 Museo Paleontológico Virtual de la Universidad de Jaén.

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DECLARATION OF COMPETING INTERESTS

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

AUTORIA CRediT

Javier Cardenal: Data curation, Formal Analysis, Methodology, Software, Writing - original draft; **Matías Reolid:** Data curation, Formal Analysis, Writing - original draft., Writing - review and editing

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