

Trace fossils and dubiofossils from the Ediacaran and Cambrian of the Alcudia Anticline, Spain

Pistas fósiles y dubiofósiles del Ediacárico y Cámbrico del Anticlinal de Alcudia, España

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ABSTRACT

The fossil record of the Ediacaran—Cambrian transition in Spain provides potentially useful information to understand this critical episode in the history of life on Earth. In the present work, new findings of trace fossils and dubiofossils are described from the upper Ediacaran and lowermost Cambrian of the Alcudian unit in the Alcudia Anticline, at the southern margin of the Central Iberian Zone (valle de Alcudia, Iberian Massif, Spain). Two new trace fossil sites are described from the Upper Alcudian subunit and assigned to the Fortunian stage (lower Cambrian, Terreneuvian series) and to the regional Lower Corduban substage. They contain examples of arthropod-like scratches (*Monomorphichnus lineatus*), small bilobed trails (similar to *Archaeonassa*), an inclined burrow with spreite (may be a teichichnid), and long unbranched burrows with very fine transversal structure (probably the ventral surface of *Psammichnites*). *Torrowangea* aff. *rosei* and possible body fossils of late Ediacaran age are described from the Lower Alcudian subunit, including a disc resembling a frond holdfast and a diamond-shaped complex structure with no known equivalents.

Keywords: Iberian Massif; Lower Cambrian; Precambrian–Cambrian transition; Terreneuvian.

RESUMEN

El registro fósil de la transición Ediacárico—Cámbrico en España proporciona información potencialmente útil para entender este episodio crítico de la historia de la vida en La Tierra. El presente trabajo describe nuevos hallazgos de icnofósiles y dubiofósiles del Ediacárico superior y Cámbrico basal en la unidad Alcudiana del Anticlinal de Alcudia, hacia el margen meridional de la Zona Centroibérica (valle de Alcudia, Macizo Ibérico, España). Dos localidades con pistas fósiles son descritas para la subunidad Alcudiana Superior, y asignadas al piso Fortuniano (Cámbrico inferior, serie Terreneuviano) y al subpiso regional Cordubiano Inferior. Contienen ejemplos de marcas de artrópodos u organismos similares (*Monomorphichnus lineatus*) y pistas bilobadas simples (semejantes a *Archaeonassa*), una madriguera con *spreite* inclinada (quizá un teichichnido) y madrigueras largas, sin ramificar, con estructura transversal muy fina (probablemente la superficie ventral de *Psammichnites*). Se describen *Torrowangea* aff. *rosei* y posibles fósiles corporales de edad ediacárica tardía en la subunidad Alcudiana Inferior, incluyendo un disco semejante al anclaje de un fronde, y una estructura compleja, con forma de diamante, sin equivalentes conocidos.

Palabras clave: Macizo Ibérico; Cámbrico inferior; Terreneuviano; Transición Precámbrico-Cámbrico.

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Introduction

The transition from the Precambrian biosphere, dominated by microorganisms, to the Phanerozoic world, where animals are a keystone group from a biogeochemical and evolutionary perspective, is arguably the deepest ecological change in the history of life on Earth (Crimes, 1992; Fedonkin *et al.*, 2007; Seilacher, 2007). This revolution was mainly concentrated in the Ediacaran—Cambrian transition, whose fossil record in central Spain is not very abundant but quite diverse, containing stromatolites, trace fossils, soft-bodied organisms (vendotaenids, sabelliditids, acritarchs, possible *Beltanelliformis*), and early skeletal fossils (*Cloudina*, *Sinotubulites*, Cambrian “small shelly fauna”, archaeocyathans, early trilobites...) (Liñán & Palacios, 1987; Vidal *et al.*, 1994;

Liñán *et al.*, 2004; Fernández-Remolar & García-Hidalgo, 2005; Jensen *et al.*, 2007; Zhuravlev *et al.*, 2012; Jensen & Palacios, 2016). In the Central Iberian Zone (CIZ), the Ediacaran—Cambrian transition is recorded in several rock units which have received different names depending on the region and author (Nozal Martín *et al.*, 1988; Vidal *et al.*, 1994; Pieren Pidal, 2000). The present work deals with the Alcudian unit (Alcudiense, as described by Crespo & Tamain, 1971) in its typical region, the Alcudia Anticline of the valle de Alcudia (Ciudad Real, Sierra Morena), at the southern margin of the CIZ (Fig. 1; after Pieren Pidal, 2009).

The axis of the valle de Alcudia is the Lower Alcudian subunit, a thick (4,000–6,000 m), generally subvertical, usually flysch-like alternation of greywackes and siltstones representing turbidites

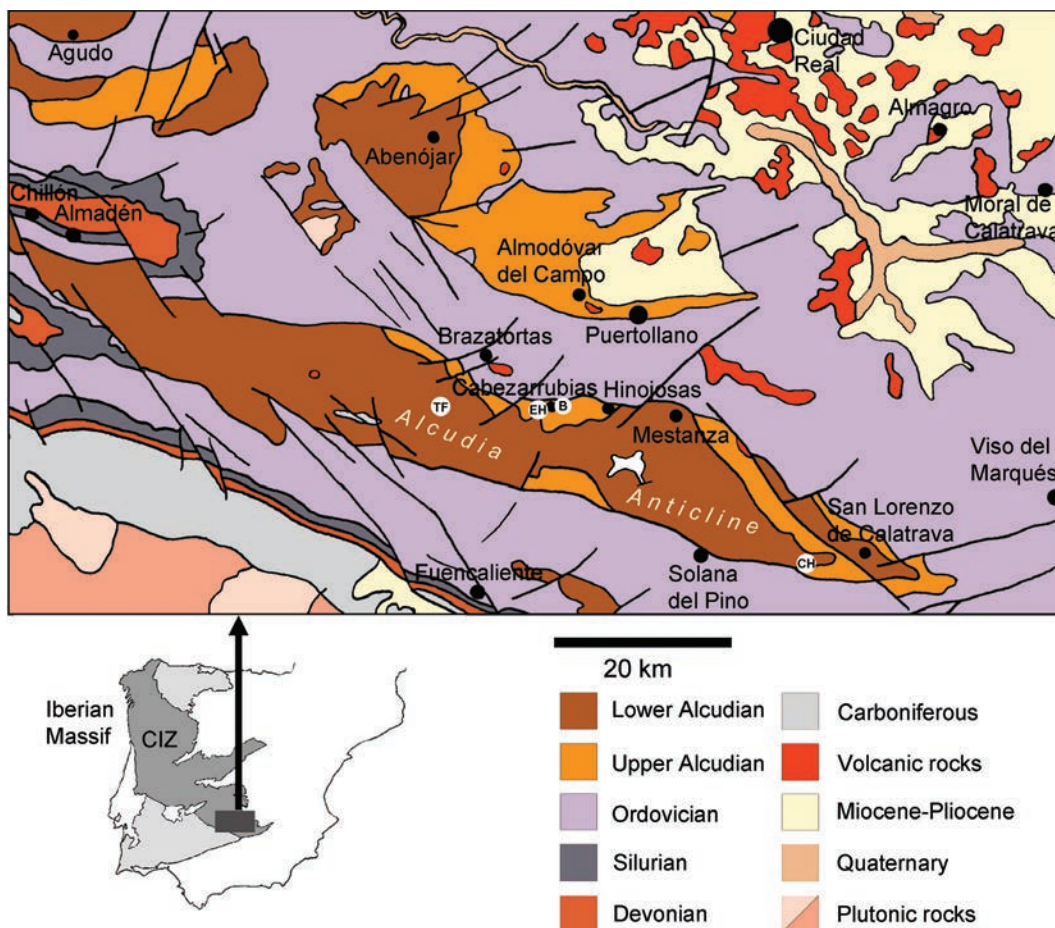


Fig. 1.—Geological map of the region of the Alcudia Anticline. CIZ = Central Iberian Zone. White circles indicate fossil sites described in the results: B = Arroyo del Barranco; TF = Tiesa Ferrer; EH = El Hontanar; CH = El Chorrillo. Main map redrawn after Pieren Pidal (2000, 2009). The trace fossils of Fig. 3 come from two localities within the circle EH (see the corresponding figure caption).

and gravitational breccias of probable late Ediacaran age, being younger than about 580–560 million years (Ma) according to radiometric geochronology using detrital zircons (Talavera *et al.*, 2015). This subunit is considered to have been deposited on a continental slope (Pieren Pidal, 2000; 2009). Most of the Lower Alcudian is so fractured and folded that conventional stratigraphic study seems impossible. Its rocks are weakly metamorphosed, corresponding to the low and occasionally high anchizone (Pieren Pidal, 2000; 2009). This subunit is overlain by the Upper Alcudian, in angular unconformity (< 550–540 Ma according to Talavera *et al.*, 2015).

Upper Alcudian beds tend to be much less distorted, suffered less metamorphism, and contain a wide range of lithologies, with frequent conglomerates. In the Alcudia Anticline, this subunit was divided by Pieren Pidal & García-Hidalgo (1999) into five formations which are interpreted to record sedimentation in a shallow siliciclastic platform. From bottom to top, these formations (Fm.) are the Tamujar, Hinojosas, Cabezarrubias (Pizarras de Cabezarrubias), San Lorenzo (Conglomerados de San Lorenzo), and Upper Formation (Pizarras Superiores) (Fig. 2). The nature of their contacts is still quite open to debate. Carbonate lenses are present in the Hinojosas Fm. (Pieren Pidal, 2000, 2009).

Up to date, the fossil record of the Lower Alcudian is restricted to a single report of sphaeromorph acritarchs in an unpublished work by Mitrofanov & Timofeev (1979, cited from Pieren Pidal, 2009). The Upper Alcudian starts with hints of bioturbation in the Tamujar Fm. (Pieren Pidal, 2000). The Hinojosas Fm. has yielded the richest fossil assemblage of the Alcudia Anticline (García-Hidalgo, 1993; Pieren Pidal, 2000), consisting on varied trace fossils. In the northern flank (Cabezarrubias-Hinojosas zone, Fig. 1), the Hinojosas Fm. have simple unbranched burrows (*Planolites*), arthropod scratches (*Monomorphichnus lineatus*), and possible treptichnids assigned to *Hormosiroidea canadensis*. The presence of *Monomorphichnus* indicates a Cambrian age (Liñán *et al.*, 1984; Gámez-Vintaned & Liñán, 1996, 2007). In the southern flank of the anticline (Macizo de Valdoró area), this formation contains simple traces with loops (*Gordia molassica*), and meandering bilobed traces initially identified as *Taphrhelminthopsis* but reinterpreted by Jensen

& Palacios (2016) as possible *Psammichnites circularis*. However, according to the diagnosis of *Taphrhelminthopsis*, this ichnogenus refers to traces that are usually big (1–3 cm wide) and very long, whereas the bilobed trails of the Hinojosas Fm. are small (~4–5 mm wide) and not very long (see photograph 4 in Pieren Pidal, 2009). Thus the ichnogenus *Archaeonassa* (1–7 mm wide) seems more adequate for these trails (see the diagnoses of both ichnogenera in Häntzschel, 1975). An example of *Archaeonassa* from the upper Ediacaran of the White Sea region (figure 3 in Jensen, 2003) in fact looks very similar to these bilobed traces in size and path.

Above the Hinojosas Fm., possible cnidarian burrows (reported as *Bergaueria* aff. *langi*) and *Planolites* have been found in the Cabezarrubias Fm. The San Lorenzo Fm. contains the early mollusks *Anabarella plana* and undescribed members of the family Coreospiridae (previously Latouchellidae). Phosphatized remains of the Tommotian species *Anabarella plana* are extremely abundant in some massive mudstone beds of the Upper Fm. (Vidal *et al.*, 1999; Pieren Pidal, 2009).

Material and methods

The specimens have been studied in outcrop when they appear in hard rocks and extensive beds that make them uncollectable without high risk of damage. They were photographed using a Canon EOS 550D and Canon EOS 7D DSLR cameras with a zoom lens Canon 18–55mm f3.5–5.6 ISII, and macro lenses Canon 60mm f2.8 and Canon 100mm f2.8. Collected specimens are deposited in the Museo de Paleontología de Castilla-La Mancha (Cuenca, Spain) under accession numbers MPCM-VA-0001 to MPCM-VA-0005.

Results

Cambrian trace fossils

New Cambrian traces for the Alcudia Anticline were found in two localities. The first one is El Hontanar (Fig. 1), southwest of Cabezarrubias del Puerto (main surface at coordinates N 38° 36' 44" W 4° 11' 40"), in the type section of the Hinojosas Fm. (Camino de Cotofia, Pieren Pidal, 2000, 2009). Most of the trace fossils appear in a

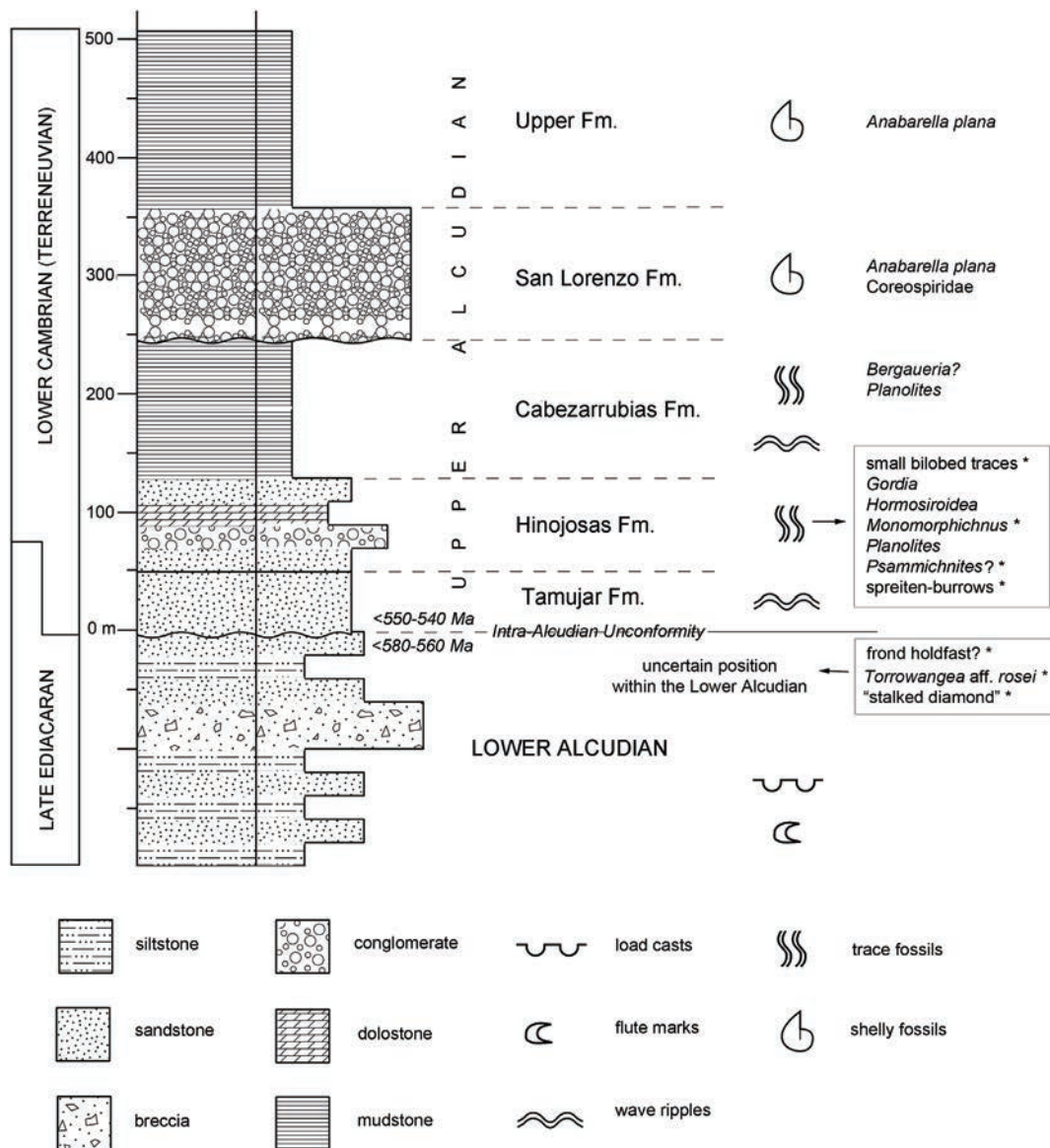


Fig. 2.—Simplified stratigraphic log of the Alcudian unit in the valle de Alcudia, showing only main rock types in each formation - bed sequence and thickness within each formation is arbitrary. Thickness of Upper Alcudian formations is approximately the same of the type section of each one, but the thickness of the Lower Alcudian is about 4,000-6,000 m. The asterisk indicates material described in the present work. Based on information from Pieren Pidal (2000; 2009).

bed top of a sequence of subhorizontal mudstone beds (Fig. 3A). Bioturbation was so intense (e.g. Fig. 3E, F) that the recognition of individual traces is difficult. However, three types of traces can be distinguished:

I) Small bilobed trails: abundant, 2–3 mm wide, with a central furrow and two lateral ridges, sometimes meandering (as in Fig. 3D). Their small width and limited horizontal development suggest the ichnogenus *Archaeonassa* instead

of the wider (1–3 cm) and mostly very long *Taphrhelminthopsis* (Häntzschel, 1975).

II) Series of subparallel grooves preserved in the bed top (Fig. 3C), interpreted as scratches of possible arthropods and assigned to *Monomorphichnus lineatus* (Crimes *et al.*, 1977). There are several specimens in the main surface; the best preserved one is shown in Fig. 3C.

III) One vertical section of what appears to be an inclined burrow with spreite (Fig. 3B). It is about

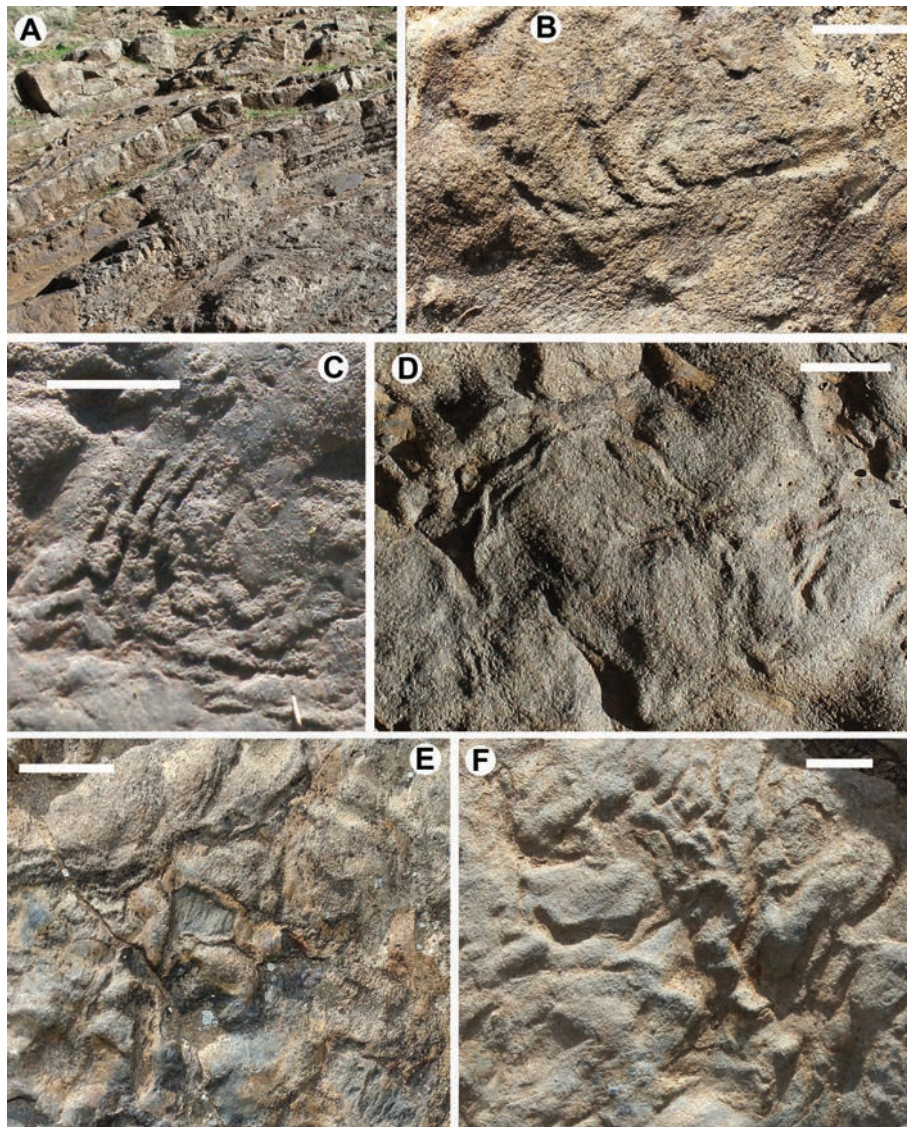


Fig. 3.— El Hontanar trace fossil site. A. Exposure of mudstone beds; one of the upper bed tops contains the fossils illustrated from 3B to 3E. B. Oblique section of a spreiten-burrow showing some crescent-shaped units of a possible teichichnid. C. *Monomorphichnus lineatus* consisting on four scratch marks preserved as grooves in the bed top. D. Small meandering bilobed trail similar to *Archaeonassa*. E. Intense bioturbation showing trails (top) and burrows (centre). F. Bioturbation with many burrows of uncertain identification, sometimes with helicoidal-like distortion. Photograph F comes from a mudstone bed top about 75 meters north of the main outcrop, in the slope of the western bank of a stream that crosses the Hinojosas Fm. Field photographs. Scale bars = 1 cm.

4 cm long and contains crescent-shaped units of decreasing size and about 1 cm of maximum width. The trace is similar to *Teichichnus*, the simplest spreiten-burrow, but the poor preservation recommends no assignation further than possible teichichnid.

The second trace fossil locality is the Arroyo del Barranco outcrop (Fig. 4), southeast of

Cabezarrubias (N 38° 36' 46" W 4° 10' 40"), in a section with carbonate lenses, again in the Hinojosas Fm. according to Pieren Pidal (2000). Next to the stream, a mudstone boulder was found with a surface plenty of burrows about 8 mm wide and sometimes more than 20 cm long. They are preserved as unilobed and unbranching positive reliefs whose infill shows very fine transverse striation in the best preserved stretches (Fig. 4B, arrow). The traces are

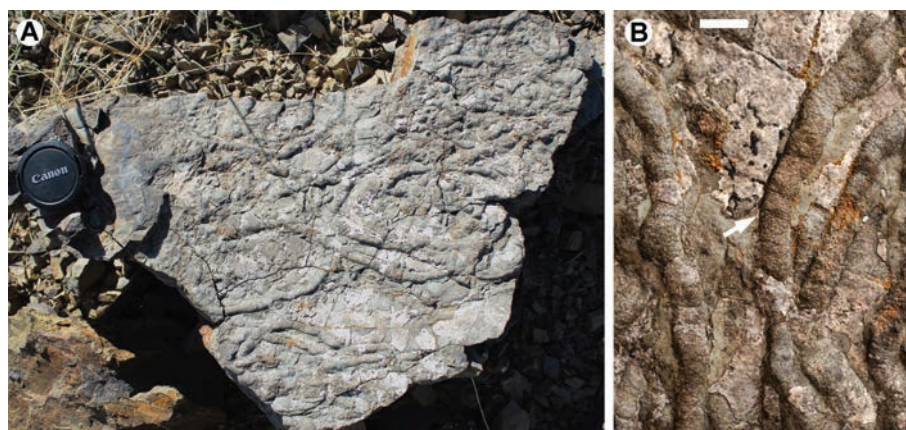


Fig. 4.—Boulder with possible ventral surfaces of *Psammichnites* from the Arroyo del Barranco locality (MPCM-VA-0001). A. Field photograph of the burrow system. Lens cap diameter = 58 mm. B. Close-up of some burrows showing very fine transversal striation (arrow). Scale bar = 1 cm.

predominantly horizontal and gently curved, and they often cross each other.

All these characteristics suggest the burrows represent the lowermost surface of *Psammichnites* (Seilacher, 2007). However, the ventral morphology of this ichnogenus can be highly variable and so it was not considered to be diagnostic by Mángano *et al.* (2002). In the emended diagnosis of *Psammichnites*, these authors referred to the bilobed upper surface only. Thus the traces of Fig. 4 do not meet the complete diagnosis of the ichnogenus, and so they are better described as very possible *Psammichnites*. The burrows resemble a smaller version of some specimens reported as *Scolicia* (but they are probably the ventral expression of *Psammichnites*) from the Lower Cambrian of the Azorejo Fm. in the Toledo Mountains (Moreno *et al.*, 1976, their figures 3d and e).

Ediacaran structures

In Lower Alcludian beds, a number of structures were discovered which resemble Ediacara-type soft-bodied fossils, but their biogenicity is problematic. A complex discoidal structure (Fig. 5B) was found in the sole of a coarse-grained turbidite immediately below the intra-Alcludian unconformity of El Chorrillo (Solaniilla del Tamaral, Fig. 1) described by Palero (1993) and dated by Talavera *et al.* (2015), who found it to be younger than 580 ± 7 Ma using detrital zircon radiometric geochronology. The disc is very similar to the holdfast of an Ediacaran frond such as *Charniodiscus*, but ultimate proofs

of biogenicity are lacking. The surface around it shows probable deep oscillation ripples but not a single similar disc was found in the outcrop.

The other structures come from the Tiesa Ferrer area (Almodóvar del Campo, Fig. 1), one of the least distorted exposures of the Lower Alcludian in the valle de Alcludia. These subvertical beds (Fig. 5A) contain silty Tc-d turbidites, 1–2 cm thick (Pieren Pidal, 2000), whose bedding planes are coated with iron oxides and show a texture similar to the Textured Organic Surfaces (TOS) typical of fossil-bearing beds in many Ediacaran sites (Gehling & Droser, 2009). This kind of surface and bed provided the object of Fig. 6, which was found in a debris pile immediately below a series of these turbidites (thus its way-up is not clear). It is the convex cast of a diamond-shaped sheet showing a diagonal groove apparently connected to a tubular structure. Some rings can be seen in this “stalk”. There are rib-like ridges extending from the diagonal axis outwards. The sheet display hints of an internal complex structure (serial branching?). The distinctive feature of the upper corner of the “diamond” suggests the sheet was folded backwards after it pressed the sediment surface. Overall, this “stalked diamond” appears to be the cast of a soft-bodied organism, but it would be highly unusual and, after extensive search, no similar objects were found in the outcrop.

In some instances, this type of thin turbidites contains filamentous structures in the TOS-like top surfaces (Fig. 5C–D, some other specimens examined in the field). They are tiny strings about 0.5–1 mm wide

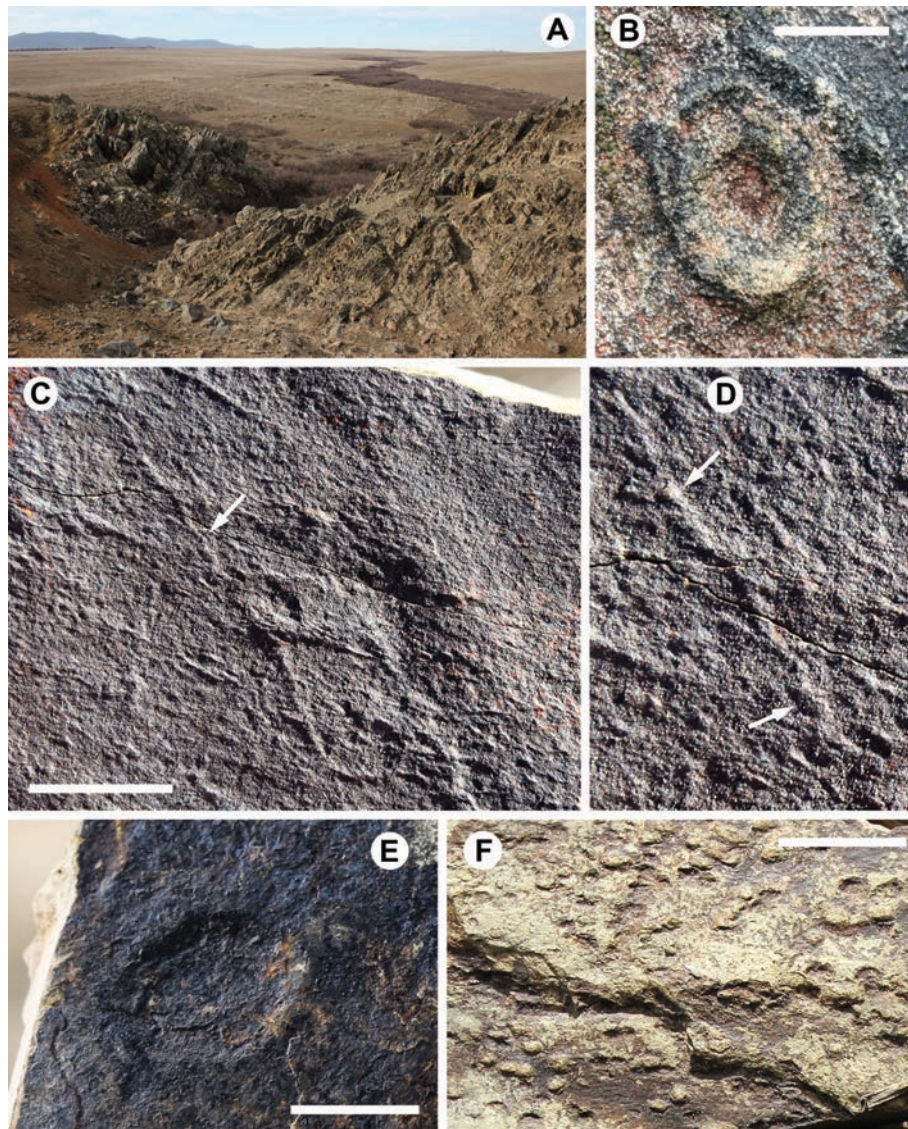


Fig. 5.—Late Ediacaran structures from the Alcudia Anticline. A. Turbidite outcrops crossed by the Tablillas river in the Tiesa Ferrer area. B. Discoidal hyporelief that could be a frond holdfast. C. *Torrowangea* aff. *rosei* (arrow) from the top of a thin silty turbidite coated with iron oxides (MPCM-VA-0002). D. Detail of *Torrowangea* aff. *rosei* from the previous image, showing small-scale meandering (lower arrow), and irregular constrictions originating pod-like segments (upper arrow and slightly above the lower arrow). E. Rimless concavity in a bed top, interpreted as a Longmyndian *Beltanelliformis*-like pseudofossil (MPCM-VA-0003). F. “Peanut blister” in a bed top (MPCM-VA-0004). Field photographs. Scale bars = 1 cm.

and up to 3 cm long, sometimes with small meanders (Fig. 5D, lower arrow) and irregular constrictions that eventually originate pod-like segments (see examples in the upper arrow of Fig. 5D and slightly above the lower arrow). These characteristics fit the diagnosis of the ichnogenus *Torrowangea* (Webby, 1970). The filaments are assigned to *Torrowangea* aff. *rosei*, a form described by Liñán & Palacios (1987) from late Ediacaran fine-grained beds of the Domo Extremeño

Group in the nearby Cáceres province. Other occurrences of *Torrowangea*, also from the Domo Extremeño Group, come from the Estenilla and Cíjara Formations in the Río Huso section (Gámez-Vintaned, 1996; Jensen & Palacios, 2016). The interpretation of *Torrowangea* aff. *rosei* is problematic since it may be a simple trace fossil, a microbial filament, or the remains of a tubular organism (Jensen & Palacios, 2016). The presence of small-scale meandering in the

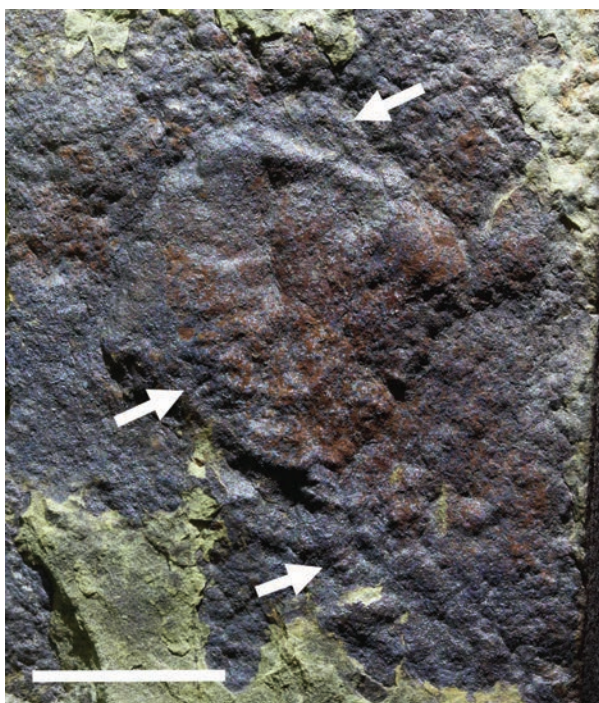


Fig. 6.— A possible soft-bodied fossil from the late Ediacaran of the Alcudia Anticline (MPCM-VA-0005). Upper arrow, imprint of a corner of the main sheet that was apparently folded backwards before lithification. Middle arrow, hints of internal structure. Lower arrow, tubular “stalk” with rings. Field photograph. Scale bar = 1 cm.

present material could support a trace fossil interpretation, but additional specimens would be necessary to sustain this conclusion.

A significant microbial coating in these Ediacaran pre-turbidite bottoms is suggested by the finding of a number of ellipsoidal, rimless, concave epireliefs (Fig. 5E) very similar to some pseudofossils of the Longmyndian Group (England). Menon *et al.* (2015) demonstrated these *Beltanelliformis*-like concavities to be pseudofossils originated by the small-scale sinking of a sand cone after an upwards fluid injection obstructed by a microbial mat. Other structures suggesting substantial microbial development in the same kind of bed tops consist on “bubbles” (Fig. 5F) resembling the “peanut blisters” that Seilacher (2007) interpreted as gas escape structures in ancient microbial mats.

Discussion

The sedimentary environment inferred for the Cambrian trace fossils here described is the shallow platform where the Hinojosas Fm. was deposited

(Pieren Pidal, 2000, 2009). The carbonates and abundant bioturbation point to low sedimentation rates. Age is constrained by the presence of *Anabarella plana* in overlying beds (Fig. 2). The age of this mollusk species ranges from about 535 to 531 Ma according to Gubanov & Peel (2003), which implies a Fortunian stage (Cambrian stage 1) for the ichnofossil locality, if the base of the stage 2 is at about 529 Ma as indicates the GSSP Table of the International Commission on Stratigraphy (consulted in June 5th 2017). In the regional chronology, this corresponds to the Lower Corduban substage (see its definition in Liñán *et al.*, 2006).

The possible taxonomic affinities of the organisms which created the traces of El Hontanar and Arroyo del Barranco are varied. *Monomorphichnus lineatus* corresponds to arthropods or arthropod-like organisms (Crimes *et al.*, 1977). As a possible teichichnid, the spreiten-burrow could have been excavated by annelid-grade vermiform creatures, or arthropods (Seilacher, 2007). In the original description of *Archaeonassa*, Fenton & Fenton (1937) showed that it closely resembles modern trails of the gastropod *Littorina*, and thus early mollusks (may be *Anabarella plana* or a similar species), or the mollusk-like halkieriids, could have produced the small bilobed trails of Fig. 3D. Seilacher & Gámez-Vintaned (1996) argued that the *Psammichnites* organism was an infaunal, soft-bodied, vermiform animal which bulldozed the sediment and had a “snorkel” appendage that protruded and collected food on the seafloor (Seilacher, 2007). The taxonomic affinity of such an organism is open to debate and may be close to mollusks or proboscis-bearing “worms”.

The Cambrian traces here described could belong to the lowermost Cambrian ichnozone (that is, the *Treptichnus pedum* + *Monomorphichnus lineatus* Zone in Spain, and the global and probably equivalent *Treptichnus pedum* Zone, see Narbonne *et al.*, 1987; Gámez-Vintaned & Liñán, 2007). However, the time spans of these traces extend into younger zones, and so they could as well represent the second Cambrian ichnozone (the global *Rusophycus avalonensis* Zone and the very similar Spanish *Rusophycus avalonensis* + *Rusophycus bonnarensis* Zone; Narbonne *et al.*, 1987; Gámez-Vintaned and Liñán, 2007). This is the ichnozone information provided by the Cambrian traces:

- *Monomorphichnus lineatus* first appear in the lowermost Cambrian ichnozone (Liñán *et al.*, 1984; Narbonne *et al.*, 1987; Gámez-Vintaned & Liñán, 2007).
- The FAD of spreiten-burrows in Newfoundland and Spain (*Teichichnus* in both cases) is in the second Cambrian ichnozone (Narbonne *et al.*, 1987; Gámez-Vintaned & Liñán, 2007). However, burrows with spreite of upper Ediacaran age have been found in the Nama Group (MacDonald *et al.*, 2014). Thus the presence of a spreiten-burrow is not diagnostic of any Cambrian ichnozone.
- Similarly, although *Archaeonassa* was described in lower Cambrian rocks (Fenton and Fenton, 1937), it first appeared in the upper Ediacaran (Jensen, 2003).
- *Psammichnites* was reported by Gámez-Vintaned (1996) to occur a few meters above the possible Ediacaran—Cambrian boundary of the Río Huso section (CIZ), very close to the first apparition of *Treptichnus pedum* and *Monomorphichnus lineatus* and so in the lowermost Cambrian ichnozone.

Regarding the Ediacaran structures here described, possible fossils comparable to the disc and the “stalked diamond” are not known for the late Ediacaran of Spain (Pieren Pidal, 2000; Jensen *et al.*, 2007; however, see a possible occurrence of *Nimbia* in Liñán *et al.*, 2009). These two structures remain as isolated findings in spite of extensive search, but rarity is not necessarily an argument against biogenicity. The reason is that well exposed bedding planes are extremely rare in the Lower Alcudian, and deep marine complex organisms probably were scarce in the latest Ediacaran after the extinction of most rangeomorphs (Xiao & Laflamme, 2009), and so very few fossil findings would not be surprising in this unit. Biogenicity seems more likely for the “stalked diamond” due to the very unusual arrangement of a ringed tubular structure with a quite symmetric sheet that displays ribs and hints of taphonomic folding and internal structure. This arrangement of different objects is very difficult to explain from an abiotic point of view. It may be a (degraded?) organism of uncertain taxonomic affinity, or an abiotic structure of unknown origin.

The occurrence of *Torrowangea* aff. *rosei* may represent the first finding of a trace fossil in the Lower Alcudian of the valle de Alcudia, if this kind of filamentous reliefs represented traces, as the possible meandering suggests. However, the options of microbial strings and tubular organisms cannot be definitely ruled out with this material. If they were trace fossils of bilateral organisms, they would imply that at least some parts of the Lower Alcudian are younger than about 555 Ma, since this is the age of the oldest unambiguous bilateral traces (Jensen, 2003; Fedonkin *et al.*, 2007). This age would be in agreement with the radiometric dating of this subunit (< 580–560 Ma according to Talavera *et al.*, 2015).

A trace fossil origin for these filaments is compatible with their occurrence as positive epireliefs, since *Torrowangea* could represent a string of faecal pellets (Liñán & Palacios, 1987). The deep marine environment is also coherent with the trace fossil hypothesis, because similarly simple traces have been described from turbidite outcrops that document the Ediacaran—Cambrian transition, for example in the Puncoviscana Formation (Buatois *et al.*, 2014). More material is required to reach any solid conclusion about the origin of all these structures.

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