Trace and soft body fossils from the Pedroche Formation (Ovétian, Lower Cambrian of the Sierra de Córdoba, S Spain) and their relation to the Pedroche event

Ichnofossiles et fossiles à corps mous de la Formation Pedroche (Ovétien, Cambrien Inférieur de la Sierra de Córdoba, sud de l’Espagne) et leur relation avec l’événement Pedroche

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Abstract

The low Lower Cambrian rocks from the Sierra de Córdoba contain one of the best successions in Europe, which consists of well exposed mixed facies showing long stratigraphical ranges throughout the Pedroche Formation. These assemblages include diverse Ovétian archaeocyaths, trilobites, small shelly fossils, calcimicrobes, trace fossils and stromatolites. Trace fossils are still poorly known, and thus they are the main objective of this work. Ichnological data are obtained from the Arroyo de Pedroche 1, Arroyo de Pedroche 2 and Puente de Hierro sections. Trace fossils include the ichnogenera Bergaueria, aff. Bilinichnus, Cochlichnus, aff. Cosmorhaphe?, Cylindrichnus, Dactyloidites, Dimorphichnus, Diplichnites, Monocraterion, Palaeophycus, aff. Phycodes, Planolites, Psammichnites, Rusophycus, Skolithos, Torrowangea and Treptichnus, as well as faecal pellets, meniscate trace fossils and others. They are abundant in shales and sandstones, and indicate important changes in the benthic conditions with respect to the underlying Torreárboles Formation. Changes in fossil assemblages within Member I of the Pedroche Formation indicate palaeoecological disruptions, which led to the disappearance of numerous archaeocyath species and the decrease of stromatolite biodiversity. This was followed by dominance of trilobite and brachiopod assemblages, accompanied by trace fossils of the Psammichnites ichnosp. A ichnoassociation. This biotic turnover (Pedroche event) occurred at the lower part of the archaeocyath Zone III, within the Bigorina bivallata biozone. The diagnoses of the ichnospecies Cochlichnus anguineus and Dactyloidites cabanasi are emended.

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Résumé

Les roches du Cambrien inférieur basal dans la Sierra de Córdoba contiennent une des meilleures successions en Europe. Elle se compose de faciès mixtes bien exposés et d’abondants assemblages de fossiles qui montrent les longues distributions stratigraphiques dans la Formation Pedroche. Ces assemblages sont composés d’archaeocyathes, de trilobites, de small shelly fossils, de calcimicrobes, de traces fossiles et de stromatolites de l’Ovétien. Les traces fossiles sont encore très peu connues et, par conséquent, elles sont ici notre principal objectif. Les traces fossiles de trois coupes sont étudiées : coupes de l’Arroyo de Pedroche 1, de Arroyo de Pedroche 2 et de Puente de Hierro. Des traces fossiles (lesquelles incluent les ichnogenres Bergaueria, aff. Bilinichnus, Cochlichnus, aff. Cosmorhaphe?, Cylindrichnus, Dactyloidites, Dimorphichnus, 

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1. Introduction

The Sierra de Córdoba is among the most important areas for understanding the Lower Cambrian palaeontology of the Iberian Peninsula. Since Hernández Pacheco (1907) found archaeocyaths in limestones near the city of Córdoba, a number of authors described additional archaeocyaths, crustaceans, trace fossils, trilobites, stromatolites, small shelly fossils, brachiopods, and soft-bodied fossils (for references see Liñán et al., 2005). In the Pedroche Formation (Liñán Guijarro, 1978), calcareous and siliciclastic beds alternate; numerous horizons bear archaeocyaths and trilobites; they are well exposed along the Arroyo de Pedroche (N of Córdoba), in one of the best Lower Cambrian successions of western Europe. Moreover, the Sierra de Córdoba is the type area for the Corduban and Ovetian stages. The biostratigraphic and biochronological units established allow international correlation with northern France, Sardinia, Morocco, Siberia, Antarctica and SW China (Perejón, 1986; Moreno-Eiris, 1987d; Pillola, 1991; Liñán et al., 2005).

The aim of this paper is to describe the ichnology of Member I of the Pedroche Formation in three selected sections (Fig. 1) where trilobites associated with archaeocyaths have been also studied, and to describe the palaeoecology of the lower Ovetian substage.

2. Geological setting

The geology of the Sierra de Córdoba was described in the classic works of Liñán Guijarro (1974, 1978) and synthesized by Perejón et al. (1996). The Neoproterozoic Volcanic–Sedimentary Complex unconformably underlies the Lower Cambrian sequence, which consists (from bottom to top) of the Torrereáboles, Pedroche and Santo Domingo formations.

The Torrereáboles Formation is composed of conglomerate, sandstone, arkose and shale. Three Corduban ichnoassemblages were described by Fedonkin et al. (1985). The first one contains Cochlichnus ichnosp., Planolites ichnosp. and Skolithos ichnosp., and the second Phycodes pedum Seilacher, 1955, Phycodes palatinum (Hall, 1852), Planolites cf. beverleyensis (Billings, 1862) and Treptichnus ichnosp. The ichnological contents of both assemblages suggest a Lower Corduban age. The third ichnoassemblage is characterised by the first record of Rusophycus ichnosp. (indicative of an Upper Corduban age; Liñán et al., 1993: Fig. 3), accompanied by Bilinichnus ichnosp. and the soft-bodied metazoan Tiernavia tiernae Fedonkin in Fedonkin et al., 1985.

The Pedroche Formation conformably overlies the Torrereáboles Formation. It is composed of limestone and shale, with scarce sandstone and dolostone, and contains archaeocyaths, trilobites (aff. Bigotinella, Bigotina, Lemadaldea, Serrania, Eoredlichia and Neoredlichiaiide), brachiopods (Paterina), algae, calcimicrobes (Renalcis and Epiphyton), small shelly fossils, bradoriids, hyolithids, columnar stromatolites (Vetella cf. sarratae Schmitt, 1979, Charaulachia cordubensis Schmitt, 1983 and Vetella nodosa Schmitt, 1983, all defined at the Arroyo de Pedroche 1 section), trace fossils (Bergaueria, aff. Bilinichnus, Cochlichnus, aff. Cosmorhaphe?, Cylindrichnus, Dactylocrises, Dimorphichnus, Diplichnites, Monocraterion, Palaeophycus, aff. Phycodes, Planolites, Psammichnites, Rusophycus, Skolithos, Torrowangea, Treptichnus, faecal pellets, meniscate trace fossils and others), and the probable soft-bodied coelenterates Tiernavia and aff. Tiernavia. Fossil assemblages suggest an early Ovetian age for the Pedroche Formation.

The Santo Domingo Formation conformably overlies the Pedroche Formation and is composed of red shale, dolostone and chert-bearing limestone. Scarce small shelly fossils, stromatolites (Stratifera), calcimicrobes (Renalcis) and brachiopods have been reported from the Member Orive (García-Hernández and Liñán, 1983).

The Castellar Formation lies conformably above the Santo Domingo Formation and is composed of sandstone and conglomerate with trace fossils. It records the uppermost Lower Cambrian.

Basal sandstones and siltstones of the conformably overlying Los Villares Formation contain Middle Cambrian trilobites and trace fossils (Liñán Guijarro, 1978; Liñán et al., 1995; Liñán Guijarro et al., 2004).

3. Stratigraphy and biochronology

The ichnofossils studied herein were collected from Member I of the Pedroche Formation at three sections (Figs. 3–5). The Puente de Hierro section (PH) is the classic locality where early Lower Cambrian trilobites of Sierra Morena were
first discovered (Liñán Guijarro, 1974, 1978). It is located at the intersection between the Arroyo de Pedroche (i.e., Pedroche creek) and the bridge of the Córdoba-Cerro Muriano railway. The fossiliferous beds belong to Member I of the Pedroche Formation, as recently pointed out by Liñán et al. (2005) (Fig. 2).

The stratigraphy of the Arroyo de Pedroche 1 section (AP1) was studied by Liñán and Dabrio (1974), Liñán Guijarro (1978), Liñán et al. (1982), Perejón (1989), and Fernández Remolar (1996, 1999). It is the type section of the Pedroche Formation (Liñán Guijarro, 1978). The section begins at the intersection between the new route of the Badajoz-Córdoba road and the right bank of the Arroyo de Pedroche, then follows the abandoned Córdoba-Cerro Muriano road which parallels the left margin of the Arroyo de Pedroche.

A recent section called Arroyo de Pedroche 2 (AP2) is located near the Club Asland Córdoba and runs parallel to the Arroyo de Pedroche 1 section (Liñán et al., 2005).

Four regional stages are currently used in studies of the Lower Cambrian of Spain. The basal, Corduban stage accounts for successions bearing Cambrian trace fossils, underlying the first Ovetian fossils assemblages (Liñán, 1984b). The Ovetian, Marianian and Bilbilian stages are defined in base of archaeocyaths and trilobites (Sdzuy, 1971; Liñán et al., 1993). For a
recent synthesis on the biochronology of the Ovetian of the Sierra de Córdoba see Liñán et al. (2005). These authors have established three trilobite interval biozones for the lower Ovetian of Sierra Morena: Bigotina bivallata Biozone, Lemdadella linarease Biozone and Lemdadella perejoni Biozone. They are limited by the first appearance datum (FAD) of the index species of each biozone, following an evolutionary lineage (i.e. interval filozones). The upper boundary of the Lemdadella perejoni Biozone is placed at the first occurrence of Eoredlichia cf. ovetensis (Sdzuy in Liñán and Sdzuy, 1978) which is a
Fig. 3. Stratigraphy of the Puente de Hierro section (modified from Liñán Guijarro, 1978).

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<tr>
<th>LOWER OVERTIAN</th>
<th>Age</th>
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<tr>
<td>PEDRÓCHE (MEMBER 1)</td>
<td>Fossiliferous horizon</td>
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<td>Lemadella tinareseae</td>
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<td>Lemadella aff. tinareseae</td>
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<td>Raspophycus diaphus</td>
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young descendant of this lineage (Liñán et al., 2005). According to these authors, the *B. bivallata* and *L. linaresae* Biozones correlate to Zone 0 of Morocco, and the *L. perejoni* Biozone to Zone I (*F. tazemmourtensis* Zone). The three Spanish biozones probably correspond to the Lower Atdabanian Stage of Siberia and correlative beds on the East European Platform and in Ant-
4. Systematic palaeontology

4.1. Coelenterata

The material studied herein is housed in the Museo Paleontológico de la Universidad de Zaragoza-Gobierno de Aragón at Zaragoza, Spain, under references MPZ 2002/844 and MPZ 2002/923.

Class INCERTAE SEDIS
Genus Tiernavia Fedonkin in Fedonkin Liñán and Perejón, 1985.
Type species: Tiernavia tiernae Fedonkin in Fedonkin Liñán and Perejón, 1985.

Tiernavia tiernae Fedonkin in Fedonkin et al., 1985.

Material: One specimen preserved as a convex mould in claystone (MPZ 2002/923).

Description: Fossil subcircular in outline, cup-shaped, with a truncated apical (lower) end surrounded by two narrow annular depressions. Diameter is ca. 15 mm and height is 6.3 mm.

Interpretation and discussion: Tiernavia is a soft-bodied fossil described from Lower Cambrian lutites of the upper Julia Member of the Torreárboles Formation in Sierra de Córdoba. Fedonkin (in Fedonkin et al., 1985) interpreted Tiernavia as moulds of imprints left by sessile, soft-bottom dwelling, polyps. Our specimen is incomplete, but the determination is still possible.

Stratigraphical distribution and biochronology: Arroyo de Pedroke 1 section, level 9 (upper part, above the Pedroke event). Lower Ovetian.

aff. Tiernavia

Material: One specimen preserved as a convex mould in a siltstone bed (MPZ 2002/844).

Description: Bag-shaped fossil with a lower, somewhat flattened hemispherical expansion (25 mm in diameter) ornamented with small tubercles (1 mm in width), which is separated from an upper part by a sharp narrowing (15 mm in diameter). The upper part of the fossil (27 mm in width) shows three lobes on one side (the other one is not visible) separated by longitudinal furrows (arrow in Fig. 6(5)). The total length of the fossil (measured almost horizontally) is 38 mm; the present vertical dimension is 11.2 mm.

Interpretation and discussion: The interpretation of this body fossil as a trace fossil is not plausible due to its sharp narrowing, the ornamentation and the type of preservation. In turn, these features point to the mould of the impression left by a sessile, endosedimentary soft-bodied animal (probably of cnidian affinities) preserved in situ. The original orientation could be more or less vertical, appearing today near the horizontal due to compaction flattening. Although this fossil shows a quite distinctive morphology, the scarcity of material (one specimen) prevents against defining a new taxon, and thus it is placed in open nomenclature, tentatively close to Tiernavia, which is the closest form known.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

4.2. Trace fossils


Ichnogenus Bergaueria Prantl, 1946.
Type ichnospecies: Bergaueria perata Prantl, 1946.

Diagnosis: Bag forming or cylindrical protruberances on the lower surface of the bedding plane. The surface of these protruberances is smooth (from Prantl, 1946).

Bergaueria perata Prantl, 1946.

Material: Two specimens preserved as full relief in siltstone (MPZ 2002/742 and 845).

Description: Bergaueria wider than deep, vertical to oblique, with thinly lined, parallel burrow walls and a lower termination which is either rounded or show a central knob (Fig. 6(1)). Transverse section is near circular; both fine and strong transverse constrictions are present on the wall. The largest specimen is 22.7 mm in diameter and 17.3 mm deep. The uppermost part of the cylinder of specimen MPZ 2002/742 (18 mm in diameter) is surrounded by an outer circular band with concentric structure (28.5 mm in diameter) that extends downwards forming a flat funnel 6.3 mm in height (Fig. 6(2)).

Interpretation and discussion: Despite the presence of transverse constrictions (a feature related to the burrowing technique) and the absence of radial depressions (a non-diagnostic character, yet common), we find advisable to classify this form as B. perata. This also applies to the central cylinder of specimen MPZ 2002/742 (18 mm in diameter) is surrounded by an outer circular band with concentric structure (28.5 mm in diameter) that extends downwards into the soft sediment. Other ichnospecies of Bergaueria (and Conostichus) have very distinctive features which are lacking in our material.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

**Type ichnospecies:** *Bilinichnus simplex* Fedonkin and Palij in Palij et al., 1979.

aff. *Bilinichnus*.

**Fig. 7(9).**

**Material:** Two specimens preserved as convex hyporelief in siltstone (MPZ 2002/863 and 896).

**Description:** A pair of two blunt, parallel ridges of uneven longitudinal profile (i.e. the height varies) separated by an irregular to slightly concave area. Each ridge seems to be composed of segments aligned in a row or slightly imbricated, which renders a pelletoidal appearance. The width is equal for each ridge of the pair (0.5 mm) and is uniform along the path, which is gently sinuous or curved. Spacing between the two ridges of specimen MPZ 2002/863 varies along its path from 1.7 to 2.6 mm and then to 1.7 mm. The area in between is slightly concave and of anastomosed texture (Fig. 7(9)). Specimen MPZ 2002/896 shows a constant spacing between the two ridges (1.5 mm) and the area in between is irregular. This specimen is actually composed of two paths aligned into an arch but overlapping at the junction. The two specimens are 28 and 34 mm long, respectively.

**Interpretation and discussion:** These ichnofossils strongly resemble *Bilinichnus* by their general morphology, dimensions and mode of preservation. However, *Bilinichnus* displays smooth ridges of even longitudinal profile and is interpreted as an exogenous trail (Fedonkin, 1981). We compare our two poorly preserved specimens with *Bilinichnus* because it is present in early Lower Cambrian rocks from Sierra de Córdoba, but they could also be compared with *Diplopodichnus* because of their pelletoidal appearance (Buatois, pers. comm.). Moreover, Buatois et al. (1998) noted that imprints are not necessarily preserved in *Diplopodichnus*, and *Bilinichnus* could therefore be considered as a potential junior synonym, pending re-examination of the holotype. On the other hand, the particular texture of the area between the ridges in specimen MPZ 2002/863 recalls somehow the impressions left by some soft-bodied worms, hence its interpretation as an ichnofossil is not conclusive.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovettan.

Ichnogenus *Cochlichnus* Hitchcock, 1858.

**Type ichnospecies:** *Cochlichnus anguineus* Hitchcock, 1858.

**Diagnosis:** Simple, smooth, horizontally undulating trails and burrows. Slight vertical undulations can be present as well. The first-order path is either straight or slightly curved. Horizontal wavelength may change along the path and is markedly larger than the wave amplitude.

Gluszek (1995) emended the diagnosis of the ichnogenus, and applied the same diagnosis to the type ichnospecies *C. anguineus*. Given that several distinct ichnospecies compose this ichnogenus, it is necessary a new diagnosis.

**Description:** Simple, horizontal or vertically undulating burrows, most of them showing a straight first-order path and a few arched. The second-order path is a lax sinuous line, with index \( R \) being nearly 4. Unrectified length ranges from 10 to 65 mm, and width from 0.5 to 1.8 mm. Wave length range from 0.6 to 12.0 mm. *Cochlichnus anguineus* often cuts across previous traces, such as *Dactyloidites cabanasi* (Fig. 8(9d)) and *Treptichnus* ichnosp. A (Fig. 9(9b)).

**Interpretation and discussion:** *Cochlichnus anguineus* differs from *Cochlichnus* ichnosp. A in showing a straight first-order path, and from this point of view it is similar to *Cochlichnus* ichnosp. B described by Gámez-Vintaned and Liñán (in Van Amerom et al., 1973) from Spanish Lower Permian fine-grained volcanic ashes deposited in small ponds of fresh water, which nevertheless shows a very irregular second-order sinuous path.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, level 9 (upper part, above the Pedroche event). Lower Ovettan.

*Cochlichnus* ichnosp. A

**Fig. 10(1a).**

**Material:** Five studied specimens, four of them preserved as full relief in siltstone and very fine-grained sandstone (MPZ 2002/727, 731, 740 and 871), and one as concave semirelief in siltstone (MPZ 2002/761, 765, 775, 825, 833, 870, 872, 873, 880 and 903).

**Description:** Simple, smooth, horizontally undulating trails and burrows. Slight vertical undulations can be present as well. The first-order path is either straight or slightly curved. Horizontal wavelength may change along the path and is markedly larger than the wave amplitude.

**Interpretation and discussion:** *Cochlichnus anguineus* differs from *Cochlichnus* ichnosp. A in showing a straight first-order path, and from this point of view it is similar to *Cochlichnus* ichnosp. B described by Gámez-Vintaned and Liñán (in Van Amerom et al., 1973) from Spanish Lower Permian fine-grained volcanic ashes deposited in small ponds of fresh water, which nevertheless shows a very irregular second-order sinuous path.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, level 9 (upper part, above the Pedroche event). Lower Ovettan.

*Cochlichnus anguineus* Hitchcock, 1858. Fig. 8(9d) and Fig. 9(9b).

**Material:** Ten studied specimens preserved as full relief in siltstone and very fine-grained sandstone (MPZ 2002/761, 765, 775, 825, 833, 870, 872, 873, 880 and 903).

**Emended diagnosis:** Simple, smooth, horizontally undulating trails and burrows. Slight vertical undulations can be present as well. The first-order path is either straight or slightly curved. Horizontal wavelength may change along the path and is markedly larger than the wave amplitude.

**Description:** Simple, horizontal or vertically undulating burrows, most of them showing a straight first-order path and a few arched. The second-order path is a lax sinuous line, with index \( R \) being nearly 4. Unrectified length ranges from 10 to 65 mm, and width from 0.5 to 1.8 mm. Wave length range from 0.6 to 12.0 mm. *Cochlichnus anguineus* often cuts across previous traces, such as *Dactyloidites cabanasi* (Fig. 8(9d)) and *Treptichnus* ichnosp. A (Fig. 9(9b)).

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**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, level 9 (upper part, above the Pedroche event). Lower Ovettan.
Fig. 6. Soft-bodied fossils and ichnofossils from the Pedroche Formation. Material coated with ammonium chloride (except 1–6, and 11). Scale bars = 1 cm. 1–4. *Bergaueria perata* preserved as full relief in siltstone. 1, 2. Specimen MPZ 2002/742; 1: bottom view (note the central knob); 2: upper view (the concentric structure is visible). 3, 4. Specimen MPZ 2002/845; 3: bottom view; 4: lateral view. 5, 6. aff. *Ternavia* (MPZ 2002/844). The contour of the fossil is paralleled by white dots. 5: bottom view, the arrow points to longitudinal furrow separating two lobes in the upper part of the fossil; 6: lateral view. 7. Latex mould of aff. *Cosmorhaphe?* preserved as concave semirelief in siltstone (MPZ 2002/877). White arrow points to third-order undulation. Black arrow indicates the trilobite *Lemnadiella linaresae*.
lichnus ichnosp. A cuts across previous specimens of Dactyloïdites cabanasi.

Interpretation and discussion: As stated by Gámez-Vintaned and Liñán (in Van Amerom et al., 1993), the genus Cochlichnus needs a diagnostic revision in the light of geometrical patterns and morphometry. Stanley and Pickerill (1998) included all previous ichnospecies in C. anguineus, which is the type ichnospecies by monotypy. Fillion and Pickerill (1990) characterised C. anguineus by the absence of ornamentation. We agree with these authors in that Cochlichnus includes trails and burrows. Cochlichnus ichnosp. A described here is a smooth form which differs from both C. anguineus Hitchcock, 1858 and C. kochi (Ludwig, 1869) in having a sinuous first-order path in addition to the “regular”, smaller undulations. Moreover, our material differs from C. kochi in having an index R markedly larger (nearly 4) for the second-order waves. Nevertheless, the number of studied specimens is not appropriate for defining a new ichnospecies.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus Cosmorhaphe Fuchs, 1895.

Type ichnospecies: Cosmorhaphe simusosa (Azaeta Moros, 1933).

aff. Cosmorhaphe?

Fig. 6(7).

Material: One specimen preserved as concave semirelief in siltstone (MPZ 2002/877).

Description: Simple, horizontal trace fossil showing three orders of undulations. The first-order path is a loosely guided meander with a wavelength of 35 mm and angular turns. The second-order path is a sinuous to angulate line with wavelength ranging from 12 to 34 mm. The third-order path is sinuous with a wavelength of 2 mm and very low amplitude. The rectified length of the trace is 120 mm; width equals 1.2 mm.

Interpretation and discussion: Cosmorhaphe has only two orders of undulations, whilst our specimen shows three. The second-order undulation (which is added to the Cosmorhaphe pattern in our case) emphasises the guide of the otherwise loose first-order meanders, indicating thigmotaxis, which is a kind of behaviour also present in Cosmorhaphe but not in Cochlichnus. Following ichnontaxonomic pattern analyses from Seilacher (1977), the undulations pattern described here could be used for erecting a new ichnotaxon, which is beyond this article because of the scarce material. On the other hand, this form may also resemble physical structures (Buatois and Uchman, pers. comm.), and hence a question mark is included after the ichnogenus.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus Cylindrichnus Toots in Howard, 1966.

Type ichnospecies: Cylindrichnus concentricus Toots in Howard, 1966.

Cylindrichnus concentricus Toots in Howard, 1966. Fig. 6(1b).

Material: Two specimens preserved as full relief in very fine-grained sandstone (MPZ 2002/924 and 925).

Description: Transverse sections of short, vertical burrows, from 2.4 to 3.5 mm in diameter. Undistinct zoned fill composed of a narrow core of sandstone and a wide mantle formed by multiple concentric layers of fine-grained lutite and alternating thicknesses.

Interpretation and discussion: Liñán et al. (1995) interpreted Cylindrichnus concentricus preserved in Middle Cambrian lutites from the Los Villares Formation as endichnial, feeding and dwelling burrows produced by a semi sessile endobenthic animal within a soft substratum rich in nutrients.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus Dactyloïdites Hall, 1886.

Type ichnospecies: Dactyloïdites bulbusus Hall, 1886.

Dactyloïdites cabanasi (Meléndez in Cabanás, 1966). Figs. 8, 7(1–5, 8d) and Fig. 10(1b).


v1986. Haentzschelinia sp. ? - Diez Balda, pp. 53, Pl. VI, Fig. c.


Fig. 7. Ichnofossils from the Pedroche Formation. All photographs are bottom views, except items 2, 3 and 4. Material coated with ammonium chloride (except the sections). Scale bars = 1 cm. 1. *Dactyloïdites cabanasi* with four radial burrows (MPZ 2002/734). Top view. 2. Vertical section across bioturbated siltstone (under water). Two retrusive spreite burrows belonging to different specimens of *D. cabanasi* are shown in transverse section. The one above (b) preserves the main burrow on its final stage (arrow; MPZ 2002/798), while the one below does not (MPZ 2002/797). 3. Same sample of bioturbated siltstone, showing the shaft (arrow).
Material: Seventy-five specimens preserved as full relief in siltstone and fine to very fine-grained sandstone, visible either from the bottom or the top of the strata as well as in cross-section (MPZ 2002/712-717, 719, 720, 725, 726, 729, 734-737, 741, 743-746, 748-758, 760, 763, 764, 767-770, 772, 774, 776-779, 781, 783-788, 795-798, 800, 801, 804, 805, 813, 819, 820, 824, 826, 827, 830-832, 836-841 and 928).

Emended diagnosis: Pentaid to rosetted trace fossils composed of four to six radial, horizontal, retusive spreite burrows connected to a narrow central shaft.

Description: Radial burrows are predominantly pentaid, in number from four to six but most frequently five. Basic biometric parameters are summarised on Table 1 and Fig. 11. Spreite burrows are plane-convex to biconvex. The retusive spreite is conspicuous in cross-sections and also in bottom and top views; laminae are arranged concave up both across and along the burrows (Fig. 8(2, 3, 10)). The main burrow (central shaft) may be present (Fig. 7(3) and Fig. 8(1a, 8a)) or absent (Fig. 7(1, 5) and Fig. 8(1b)). Unweathered specimens may show faint concave striae, which trace the spreite inside; concavity points mostly toward the central shaft (Fig. 8(4)). Weathering reveals the three-dimensional architecture of the spreite (Fig. 7(1, 5) and Fig. 8(3, 10)). A narrow, longitudinal furrow may run on the lower surface of some radial burrows (Fig. 8(1a) and Fig. 10(1b)). Burrow infill may differ from the surrounding matrix. On some occasions tiny, scarce pellets are located on the proximal region of the petal (Fig. 8(4)).

Good radial symmetry is absent only in a few specimens, like the six-armed MPZ 2002/836 (Fig. 8(2)) and MPZ 2002/781 (Fig. 8(7)).

Interpretation and discussion: Dactyloidites is very abundant in the heterolithic facies of the Puente de Hierro section, composed of fine to very fine-grained sandstone and siltstone. It is absent from the prevailing fine-grained mudstones of the Arroyo de Pedroche 1 section.

The radial geometry and the spreite structure lead to interpret our specimens of Dactyloidites cabanasi as feeding burrow systems (fodiichnia) produced by soft-bodied mud eaters within nutrient-rich, soft substrata. Simultaneous occupation of a given area of substratum by a number of producers probably occurred. Specimens of Dactyloidites cabanasi may touch but do not overprint each other, thus suggesting phobotaxis. The exclusivity of retusive forms is highly compatible with soft substrata undergoing moderate but rather continuous sedimentary agradation in a shallow sublittoral setting of moderate energy. Differences in spreite convexity and ornamentation may reflect slight differences in the water contents of the mud during the process of production and early stages of burial. The higher or lower relief of the hypichnial bulge depends partially on the burrowing technique and, to a bigger extent, on the textural contrast between the exploited sediment and the underlying substratum. The maximum bulge in Dactyloidites cabanasi appears when this is produced within sediment of coarse silt to fine-grained sandstone and the bottom of the radial burrows reaches a level of underlying clay.

Our material shows a constructional pattern very close to the interpretation given by Fürsich and Bromley (1985) for the so-called Dactyloidites canyonensis (Bassler, 1941). Assuming their interpretation of Dactyloidites as a valid ichnospecies for rosetted spreite structures, we propose to transfer the ichnospecies Anthoichnites cabanasi Meléndez in Cabanás, 1966 to the ichnogenus Dactyloidites because of priority. But contrary to the opinion of Fürsich and Bromley (1985), we find not advisable to include Brooksella canyonensis Bassler, 1941 within Dactyloidites, given that the Neoproterozoic material of Bassler (1941) is still to be well understood. This is in agreement with the statement by Agirrezabala and De Gibert (2004: 204) that Brooksella canyonensis and Dactyloidites asteroides “are in need of a new systematic revision, including an assessment of their possible inclusion within the ichnogenus Dactyloidites”. Dactyloidites cabanasi differs from Gyrophyllites in lacking the helicoidal, stacked pattern of leaf-shaped feeding burrows.

Hence we find convenient to maintain the ichnospesific designation given by Meléndez in Cabanás (1966).


of the ichnospecies); Arroyo de Pedroche 2 section, level 12. Lower Ovetian.

Ichnogenus *Dimorphichnus* Seilacher, 1955.

**Type ichnospecies:** *Dimorphichnus obliquus* Seilacher, 1955.


Fig. 7(6b).

**Material:** One specimen preserved as convex hyporelief in fine-grained sandstone (MPZ 2002/790).

**Description:** Trace fossil composed of two sets, each with five or four slightly sigmoidal, raker impressions and a similar number of obscure and blunt, pusher impressions arranged parallel to those. The trace is overprinted (and to some extent obscured) by specimen MPZ 2002/791 (*Diplichnites* ichnosp. indet.). Total length of the trace is 25 mm, total width is 19 mm. Length of each raker set is 10.5 mm; width of raker sets are 11.4 and 10.0 mm.

**Interpretation and discussion:** According to Seilacher (1955), *Dimorphichnus* is a grazing trace formed by trilobites when scratching the sea bottom with the appendages in search for food. Our specimen is interrupted on its middle part by the later production of *Diplichnites*.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

_Dimorphichnus* ichnosp. A.

Fig. 7(6a).

**Material:** One specimen preserved as convex hyporelief in fine-grained sandstone (MPZ 2002/789).

**Description:** *Dimorphichnus* composed of a set of two arched, convergent, 30-mm long (unrectified) raker impressions and two blunt pusher impressions. Separation between raker impressions diminishes gradually from 4.4 to 2.0 mm.

**Discussion:** This specimen differs from *D. obliquus* in the arched path of the raker impressions, instead of sigmoidal.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus *Diplichnites* Dawson, 1873.

**Type ichnospecies:** *Diplichnites aenigma* Dawson, 1873.

*Diplichnites* ichnosp. indet.

Fig. 7(6c, 7).

**Material:** Three specimens, two of them preserved as convex hyporelief (MPZ 2002/791 and 922) and one as concave epirelief (MPZ 2002/889), all in fine-grained sandstone.

**Description:** Only one out of the three specimens is preserved complete, showing two convergent rows of tracks. The other two preserve only one row. Length of the complete specimen is 22.0 mm and width varies progressively from 12.0 to 6.7 mm; individual imprints are less than 1 mm wide. Length of each incomplete specimen is 12.5 mm, with individual imprints from 1.5 to 3.5 mm in width.

**Interpretation and discussion:** Trackways produced by trilobites walking on the sea floor. In the two incomplete specimens, appendage imprints left by one side of the body may not be preserved due to undertrace deficit preservation (cleavage relief).

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus *Monocraterion* Torell, 1870.

**Type ichnospecies:** *Monocraterion tentaculatum* Hall, 1847.

*Monocraterion* ichnosp. indet.

Fig. 9(4, 6).

**Material:** Three studied specimens, one preserved as full relief within very fine-grained sandstone (MPZ 2002/810), and two as convex hyporeliefs in fine-grained quartzite (MPZ 2002/846 and 848).

**Description:** Conical structures from 3.0 to 11.6 mm in diameter and from 2.2 to 5.2 mm in height. The two largest specimens, preserved in quartzite, show a truncated apical (lower) termination.

**Interpretation and discussion:** *Monocraterion* is interpreted as domicinia left by a variety of producers. Our specimens appear in beds deposited at moments of increasing water energy. It is noteworthy the co-existence of *Monocraterion* ichnosp. indet. with *Psammichnites gigas* together in the same sample (7 cm thick) of fine-grained quartzite (Fig. 9(6)); the former predates *Psammichnites* within a clean, sandy substrate. These specimens reflect two different feeding and living behaviours, and probably record two stages of the ecological succession posterior to the high energy, event bed.

Although Schlirf and Uchman (2004) suggest restriction on the use of *Monocraterion* to the type-material, we follow the generalised criterion of including vertical, cylindrical burrows,
Fig. 9. Ichnofossils from the Pedroche Formation. Material coated with ammonium chloride (except the section in 2). Scale bars = 1 cm. 1. Top view of two Psammichnites gigas. One specimen (b: MPZ 2002/817), coming from below, intersects another one (a: MPZ 2002/816). 2. Same as previous, in cross-section (under water). White, dotted contour: incomplete, elliptical burrow of MPZ 2002/817. Black arrows: path of the ciliated “snorkel”, inclined to the right, which produced a sinuous track (not visible on Fig. 9(1)) on top of MPZ 2002/817. White arrow: the same for MPZ 2002/816, but inclined to the left side and only partially preserved.
which are funnel-shaped at the top, in this ichnogenus, until a comprehensive revision is accomplished.

**Stratigraphical distribution and biochronology:** Arroyo de Pedroche 1 section, level 2; middle part of the Puente de Hierro section. Lower Ovetian.

**Ichnogenus** *Palaeophycus* Hall, 1847.

**Type ichnospecies:** *Palaeophycus tubularis* Hall, 1847.

*Palaeophycus* cf. *alternatus* Pemberton and Frey, 1982. Fig. 10(5b).

**Material:** One specimen preserved as full relief in very fine-grained sandstone (MPZ 2002/862).

**Description:** Simple, cylindrical, weakly lined and straight, horizontal burrow with faint, parallel longitudinal striae and over-imposed faint constrictions. Infilling stuff is the same as host rock. Diameter varies from 0.5 to 1.5 mm; length, 60 mm.

**Interpretation and discussion:** Striae and constrictions do not alternate (as in *P. alternatus* Pemberton and Frey, 1982) but rather coincide in place all along the trace fossil. Striae faintly marked and a constant diameter. The distinct morphological characteristics would make this form suitable for a new ichnospecies. Nevertheless, we consider the material collected as insufficient.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

*Palaeophycus* ichnosp. A.

**Material:** Five specimens preserved as full relief in very fine-grained sandstone and (mostly) in siltstone (MPZ 2002/853, 854, 856, 857 and 865).

**Description:** Simple, bulbous, weakly lined, straight (horizontal) or gently curved (either in the horizontal or vertical plane) burrows with distinct, regularly spaced, transverse constrictions. Infilling stuff is the same as host rock. Cross-sections are circular and diameter may change abruptly over short distances: it ranges from 2.0 to 5.0 mm; length from 9.5 to 20.0 mm.

**Interpretation and discussion:** The presence of transverse constrictions as the only burrow sculpture and the bulbous morphology prevent identifying this ichnocoenose with any of the ichnospecies of *Palaeophycus* previously recognised, including *Palaeophycus serratus* McCann, 1993 which show annules faintly marked and a constant diameter. The distinct morphological characteristics would make this form suitable for a new ichnospecies. Nevertheless, we consider the material collected as insufficient.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

*Palaeophycus* ichnosp. indet.

**Material:** Two specimens preserved as concave semi-relief in siltstone and as full relief in very fine-grained sandstone (MPZ 2002/866 and 867).

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Table 1
Summary of some biometric parameters of *Dactyloides cabanasi*(Meléndez in Cabanás, 1966) from the Pedroche Formation
Résumé de quelques paramètres biométriques de l’ichnoespèce *Dactyloides cabanasi* (Meléndez in Cabanás, 1966) de la Formation Pedroche

<table>
<thead>
<tr>
<th>Diameter (mm) [n = 71]\</th>
<th>Width of the larger radial burrow (mm) [n = 74]\</th>
<th>Height of the hypichnial bulge (mm) [n = 13]\</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>81.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>14.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Mean</td>
<td>38.8</td>
<td>11.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>11.67</td>
<td>4.35</td>
</tr>
</tbody>
</table>

Fig. 11. Histograms for some biometric parameters of the ichnospecies *Dactyloides cabanasi* (Meléndez in Cabanás, 1966) from the Pedroche Formation.

Fig. 11. Histogrammes de quelques paramètres biométriques de l’ichnoespèce *Dactyloides cabanasi* (Meléndez in Cabanás, 1966) de la Formation Pedroche.

**Description:** Simple, cylindrical, lined and straight, horizontal burrows with same infilling stuff as host rock. Diameter from 1.7 to 2.5 mm; length from 12.5 to 28.0 mm.

**Interpretation and discussion:** Poorly preservation hinders identification at the ichnospecific level.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

Ichogenus *Phycodes* Richter, 1850.

Type ichnospecies: *Phycodes circinnatum* Richter, 1853.

aff. *Phycodes*.

Fig. 6(11a).

**Material:** One specimen preserved as full relief in very fine-grained sandstone (MPZ 2002/850).

**Description:** Slightly curved burrow, 68 mm in length, of variable diameter (up to 4.5 mm), with two lateral, curved, bulbous branches up to 3.4 mm in diameter (widening distally) and 16 mm long, placed closely at the same side of the main burrow. The infilling of the burrow is darker and finer-grained than the surrounding host rock.

**Interpretation and discussion:** This specimen is a composite feeding trace showing a singular morphological pattern which is attributed to a *Phycodes-Planolites* ontogenetic transition: a main burrow develops two lateral probes and is followed by a simpler feeding behaviour. On the other hand, bulbous probes are not often found in *Phycodes*, hence reinforcing the open nomenclature status.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

Ichogenus *Planolites* Nicholson, 1873.

Type ichnospecies: *Planolites vulgaris* Nicholson and Hinde, 1875.

*Planolites annularis* Walcott, 1890.

Fig. 10(1c).

**Material:** Twelve studied specimens preserved as convex hyporelief in very fine-grained sandstones (MPZ 2002/728, 738, 739, 747, 762, 766, 780, 828, 858, 890, 891 and 917).

**Description:** *Planolites* consisting of straight or slightly curved, simple subcylindrical burrows ornamented with transversal, either closely or widely spaced, striae. Length ranges from 4 to 84 mm, and width from 0.5 to 4.6 mm. One specimen (MPZ 2002/828) shows a straight first-order path with the second order being low-amplitude waves. Specimen MPZ 2002/739 shows two straight paths linked by an abrupt turn.

**Stratigraphical distribution and biochronology:** Middle and upper part of the Puente de Hierro section. Lower Ovetian.

*Planolites beverleyensis* (Billings, 1862).

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Material: One specimen preserved as full relief in fine-grained quartzite (MPZ 2002/818).

Description: Almost straight, smooth, simple subcylindrical burrow, 40 mm long and 2.5 mm wide. Burrow fill is slightly different to the host rock.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

Planolites montanus Richter, 1937.

Fig. 10(3a, b).

Material: Sixteen studied specimens preserved as full relief in claystone, siltstone and very fine-grained sandstone (MPZ 2002/860, 868, 879, 888, 897, 899, 900, 904, 905, 906, 909, 913–916 and 918).

Description: Variably curved to undulating, simple subcylindrical burrows of length ranging from 3.4 to 20.0 mm; width ranges from 0.5 to 2.9 mm and may change along the path. Surface is usually smooth, but rounded longitudinal ridges may be present (MPZ 2002/904).

Stratigraphical distribution and biochronology: Arroyo de Pedroche 1 section, levels 2, 9 (upper part, above the Pedroche event) and 11; middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus Psammichnites Torell, 1870.

Type ichnospecies: Arenicolites gigas Torell, 1868.

Psammichnites gigas (Torell, 1868).

Fig. 9(1–3, 4b, 6b).

Material: Four specimens collected, two of them preserved as full relief at the top of a bed (MPZ 2002/816 and 817), one preserved as concave epirelief (MPZ 2002/849), and one preserved as full relief at the bottom of a bed (MPZ 2002/847). All were found in fine-grained quartzite. Additional material is in one large block of rippled sandstone which remains in the field (level AP1/9).

Description: Horizontal burrows, elliptical in cross-section, showing a complex structure which includes an axial, sinuous track on the upper levels and an axial depression on the middle levels of the trace, both preserved as cleavage relief (Fig. 9(1, 2)). The bottom of the burrow show meniscate structures (Fig. 9 (3)) and a central, straight to slightly sinuous cord (arrowed in Fig. 9(1a)). In Fig. 9(2) the cross-section shows the specimen MPZ 2002/816 disrupted and shifted upwards by the cross-over of specimen MPZ 2002/817 slightly from below (white, dotted contour on the photograph). Length of the burrows among collected material range from 60 to 175 mm, width from 12 to 21.6 mm, and preserved thickness from 2.0 to 13 mm. Specimens remaining in the field show larger dimensions (ca. 35–40 mm in width) and display lasso patterns.

Interpretation and discussion: The complex morphology of Psammichnites gigas resulted from the bulldozing of a relatively large soft-bodied marine animal (probably a flat worm) parallel to the bedding plane a few centimetres below the surface, which collected organic detritus from the sediment surface with a ciliated “snorkel” and backfilled actively the burrow (Seilacher and Gámez-Vintaned, 1995; Seilacher Drexler and Seilacher, 1999). The pendular movement of this organ combined with body motion to produce the sinuous track observed in upper levels of the trace, as the sediment was sharply cut (arrows on Fig. 9(2)). As pointed out by the cited authors, the animal possibly employed a two-level mode of feeding, inhaling oxygenated water and detrital food from the surface and pumping H₂S for bacterial chemosymbionts from the pore water.

Stratigraphical distribution and biochronology: Arroyo de Pedroche 1 section, levels 2 and 9 (lower part, below the Pedroche event); middle part of the Puente de Hierro section. Lower Ovetian.

Psammichnites ichnosp. A.

Fig. 8(1e, 5f, 6b, 8c, d) and Fig. 9(5).

Material: Sixteen specimens preserved as full relief and convex hyporelief in very fine-grained sandstone (MPZ 2002/718, 730, 814, 815, 821, 822, 834, 835, 842, 859, 864, 892, 907, 908, 911 and 931).

Description: Basic morphology is similar to that of P. gigas but differs in that burrow lining is present and size is smaller. Burrows range from 13 to 112 mm in length and from 1.2 to 11.3 mm in width. Also, the higher number of specimens permits one to reconstruct the complete set of features of the trace, which further includes fine transverse striae on the lowermost surface of the burrow, meniscate backfilling above this and an axial, straight cord (MPZ 2002/718 in Fig. 8(5f)). The axial, sinuous track is also visible from the bottom part of the trace. Specimen MPZ 2002/821 shows a sinuous path (wavelength, 62 mm) and cross over one specimen of Dactyloidites cabanasi (Fig. 8(8c)); the latter feature is observed also elsewhere.

Interpretation and discussion: Morphological similarities with P. gigas point to the same basic behaviour, but differences in size and burrow lining may give support to a separate ichnospecies.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, levels 9 (upper part, above the Pedroche event) and 11. Lower Ovetian.

Ichnogenus Rusophyccus Hall, 1852.

Type ichnospecies: Fucoides biloba Vanuxem, 1842.

Rusophyccus didymus (Salter, 1856).

Fig. 7(8a–c).

Material: Three specimens preserved as convex hyporelief on a single slab of very fine-grained sandstone (MPZ 2002/721 to 723).

Description: Shallow, coffee-bean bilobate traces with few scratch marks which are not organised into sets. The midline furrow widens to the rear (as the total width of the trace does) in one opisthocline specimen (MPZ 2002/721) and is homogeneously narrow (as is the total width) in the other two. The V-angle of marks is ca. 45° in MPZ 2002/721 and near 180°
in the others. The traces are 7.4–8.5 mm wide and 10–14 mm long. All the three appear parallel to four long, cylindrical burrows, and near two specimens of *Dactyloïdites cabanasi*.

**Interpretation and discussion:** The general shape of the traces and their tiny sizes allow the identification with *R. didymus*. Usually too faint scratch mark patterns make this ichnospecies rather poorly defined. In our case, variations within the endopodite scratch marks pattern are due to differences in the digging behaviour of the arthropod producer. Some authors considered that the holotype of *Rusophycus didymus* is probably of inorganic origin (Pickerill, personal communication in Mángano et al., 1996). Further studies on the holotype are thus needed.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section. Lower Ovetian.

Ichnogenus *Skolithos* Haldemann, 1840.

**Type ichnospecies:** *Skolithos linearis* Haldemann, 1840.

*Skolithos* ichnosp. indet.

**Description:** Isolated, simple, thin, straight to slightly winding, horizontal burrows in which thickenings and constrictions alternate. Diameter from a few tenths of millimetre up to 1.6 mm; length up to 55 mm.

**Interpretation and discussion:** These traces are interpreted as shallow feeding burrows actively infilled with pellets. The isolation and the lack of intense windings or loops prevents the identification with *T. rosei* Webby, 1970. In the absence of quick turns producing angles on otherwise straight paths, the ichnospecies *T. angulata* Gámez-Vintaned and Liñán, 1993 can also be discarded.

**Stratigraphical distribution and biochronology:** Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, levels 11 and 12. Lower Ovetian.


**Type ichnospecies:** *Torrowangea rosei* Webby, 1970.


**Fig. 10(4b, c).**

**Material:** Four studied specimens preserved as full relief in fine-grained and very fine-grained sandstone (MPZ 2002/733 and 799), three preserved as concave epirelief on fine-grained sandstone (MPZ 2002/806, 807 and 809) and one as full relief in siltstone (MPZ 2002/902).

**Description:** Straight sets of individual burrows curved horizontal to vertically of similar length arranged into a zigzag pattern; one is connected to another at their lower parts. Individual burrows are from 11.4 to 20.7 mm in length, and from 1.0 to 2.1 in width. Sets are from 22.4 to 74.0 mm, and from 5.5 to 16.0 mm in width.

**Interpretation and discussion:** The appearance of *Torrowangea* varies according to the level at which the trace is observed (a basal level is shown in MPZ 2002/806; Fig. 9(7a)), and also if viewed either from the bottom (Fig. 9(9a)) or the top of the stratum (Fig. 9(7a, 8)).

**Stratigraphical distribution and biochronology:** Arroyo de Pedroche 1 section, level 9 (upper part, above the Pedroche event); middle part of the Puente de Hierro section. Lower Ovetian.

*Treptichnus* ichnosp. B.

**Fig. 9(7b).**

**Material:** One specimen preserved as concave epirelief on fine-grained sandstone (MPZ 2002/808).

**Description:** A set of four straight individual burrows arranged into a square pattern. The set is in ontogenetic connection with a set of burrows organised into a *Treptichnus* ichnos. A pattern (Fig. 9(7b, a)). Individual burrows are from 6.8 to 14.2 mm in length, and 0.7 mm in width; the total length of the set is 27 mm, and its total width 12.5 mm.

**Interpretation and discussion:** Although this morphology would not fit strictly with *Treptichnus*, the ontogenetic continuity with *Treptichnus* ichnosp. A and the same type of bifurcation (each successive burrow branching from the distal part
of the previous one) support the inclusion within this ichno-genus.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

Undetermined burrow.

Fig. 6(8).

Material: One specimen preserved as sandy full relief within claystone (MPZ 2002/898).

Description: Trace fossil characterised by a very simple pattern composed of horizontal burrows of elliptical section, 3 mm in width and a total length of 55 mm, branching at acute angles. Ornamentation consists of fine, faint longitudinal ridges.

Interpretation and discussion: This ichnosp. A described by Gámez Vintaned and Mayoral (1995) from lutites of the Middle Cambrian Murero Formation at Murero (Cadenas Ibéricas, Spain).

Stratigraphical distribution and biochronology: Arroyo de Pedroche 1 section, level 9 (upper part, above the Pedroche event). Lower Ovetian.

Faecal pellets.

Fig. 6(10, 12) and Fig. 8(1d).

Material: Numerous specimens preserved as full relief, and as concave semireliefs, in siltstone and fine-grained, micaceous sandstone. Among them, nine items are given the references MPZ 2002/773, 803, 881-883, 885-887 and 901.

Description: Pellets can be found either grouped or scattered on the rock. Scattered pellets range from 0.2 to 4.7 mm in diameter. MPZ 2002/881, 883 and 901.

Groupings are either linear or in circles. Linear groups are either straight and simple or curved and double (MPZ 2002/886; two parallel lines are 5 mm apart), accounting for a few pellets from 0.8 to 1.8 mm in diameter each. Total length reaches up to 30 mm.

Circular groupings show 5–15 pellets each, reaching up to 14.7 mm in diameter. Diameter of pellets range from 0.3 to 1.4 mm. MPZ 2002/773, 803, 882, 885 and 887.

Interpretation and discussion: The material is interpreted as faecal pellets after its morphology, arrangement patterns and mode of preservation. Prefossilization processes (Seilacher, 2002) should be invoked for preservation of primary morphologies.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section; Arroyo de Pedroche 1 section, levels 9 (upper part, above the Pedroche event) and 11. Lower Ovetian.

Meniscate trace fossils.

Fig. 8(1c) and Fig. 10(8b).

Material: Six studied specimens preserved as full relief in siltstone (MPZ 2002/724, 759, 771, 782 and 802) and in very fine-grained, micaceous sandstone (MPZ 2002/932).

Description: Straight to slightly curved, simple subcylindrical to vertically flattened burrows with meniscate infilling of the same type as the host rock. Burrows with closely spaced menisci (Fig. 10(8b)) seem to lack lining, while those with widely spaced menisci (Fig. 8(1c)) have a thin lining. Length ranges from a few millimetres to 50 mm, and width from 1.4 to 9.0 mm.

Interpretation and discussion: The material probably includes two ichnotaxa related to Taenidium.

Stratigraphical distribution and biochronology: Middle part of the Puente de Hierro section. Lower Ovetian.

5. Palaeoenvironments and palaeoecological turnover at the Pedroche event

Sedimentological studies on the Member I of the Pedroche Formation at the Arroyo de Pedroche 1 and other sections in Sierra de Córdoba were made by Zamarreño and Debrenne (1977) and by Moreno-Eiris (1987a, 1987b, 1987c).

The base of the Arroyo de Pedroche 1 (API) section is covered by quaternary deposits. According to Perejón et al. (1996), the characteristics of the Cambrian sediments suggest a shallow carbonate platform with intermittent clastic influence, as it is recorded by the silts and sandstones, interbedded with limestones and sandy limestones (Fig. 4).

This alternation of terrigenous and carbonates is repeated throughout the section and is interpreted as a shallowing sequence. This sequence begins with terrigenous deposits, silts and sandstones, which are coarse bedded and show parallel lamination, cross-bedding and ripples. Some thin lenticular limestone beds are interbedded with terrigenous sediments.

The carbonates at top of the section are thicker and show different facies types, such as oolitic, oncotic, calcimicrobe, stromatolitic, bioclastic and mound limestones.

Oolitic limestones are often present and these grainstones constitute ooid shoals. In this section calcimicrobe limestones and mounds are present on top of the oolitic bars.

The biogenic limestones are made of several components which change according to environmental conditions. The calcimicrobe limestones are made of boundstones of Renalcis and Epiphyton, and peloidal wackestones-packstones, formed in a protected environment. Stromatolitic limestones have been found in several levels of the section, sometimes associated with scattered archaeocyaths (Schmitt, 1983).

The small mounds are formed by archaeocyaths and calcimicrobes. The cups of Protopharetra bigoti Debrenne, 1964 and Agastrocyathus gregarius Debrenne, 1961 constitute branching colonies which are related to Nochhorocyathus, Coscinocyathus, and they are surrounded by calcimicrobes such as Epiphyton, Renalcis and Girvanella. These boundstones constitute a framework, which has been previously described in Lower Cambrian of the Poleta Formation, Nevada (Rowland, 1984) and the Nebida Formation, Sardinia (Bechstädt et al., 1985).

During the algal activity and the development of the mounds on this carbonate-terrigenous platform, ooid shoals were formed, which were related to algal limestones in a protected area where terrigenous material was deposited. Small
reef mounds were developed on top of the oolitic bars. The terrigenous deposit is more important during certain episodes, until it prevails over carbonate sedimentation.

In summary, the sedimentary evolution of the Member I of the Pedroche Formation is continuous, without important breaks in sedimentation.

From a palaeoecological point of view, the upper part of the lowermost Cambrian Torreárboles Formation records the onset of widespread, open sublittoral ecosystems at the beginning of the Cambrian transgression in Sierra Morena (Liñán and Fernández Carrasco, 1984; Liñán and Quesada, 1990). Arthropods, annelids and coelenterates colonized the sea bottom, producing distinctive trace fossils (Fedonkin et al., 1985; Liñán, 1984a). Subsequently, biothermal organisms colonized the marine platform, and carbonate constructions with archaeocyaths and calcimicrobes developed during the deposition of the Pedroche Formation (Member I) (Perejón, 1975a, 1975b, 1975c, 1976a, 1976b, 1977, 1978; Moreno-Eiris, 1987d). Peri reefal communities of small shelly fossils, sponges, bradoriids and trilobites also developed in carbonate substrates, while clastic substrates accommodated soft-bodied communities producing ichnoconoes.

Archaeocyatha are well represented in the API section, where four zones were recognised by Perejón (1986, 1994). The boundary between Zones II and III represent the extinction of characteristic archaeocyath genera, followed by the radiation of new forms (Perejón, 1989).

Stromatolites spread at the lower-middle part of the Pedroche Formation (Member I) and decreased at the base of the Bigotina bivalvata biozone (Fig. 4). The decrease in stromatolite diversity during Early Cambrian times is a general trend which is also recorded in other regions of the world. In the Anti-Atlas of Morocco, it took place within the Lemdadella horizon of the Lemdad section (Sdzuy, 1978; Schmitt, 1979).

In Russia, stromatolites diversified from Vendian to Lower Atabanian in Uchur-Mayal and Anabar regions (Krylov, 1963; Komar, 1966, 1973; Semikhatov et al., 1970; Keller, 1973). The stromatolite taxa distinguished in the Arroyo de Pedroche section are Vetella cf. sarfattae, Charaulachia cordobensis and Vetella nodosa, all of them from the archaeocyath Zone II. Charaulachia and Vetella are two Neoproterozoic genera which disappeared from Morocco (High Atlas), the Siberian Platform (Charaulach and Olenek) and the Sierra de Córdoba in Early Cambrian times (Schmitt, 1979,1983).

Some ichnoassemblages from the lower part of the Arroyo Pedroche I section (levels 1 to 4) are dominated by both horizontal and short, vertical domichnia, while others show fodi-nichnia and pascichnia, all preserved in substrata of grain size from siltstone to medium sandstone, suggesting a shallow marine environment with rather clean substrata under relatively high energy conditions. Ichnotaxa of the Cruziana ichnofacies (including Psammichnites gigas) alternate here with ichnogenera typical of the Skolithos ichnofacies (Fig. 4), reflecting short-term, alternating energy conditions which produced different grain-sizes in substrata.

Ichnotological data are very scarce from the middle part of the section. In the upper part (archaeocyath Zone III), ichnoassemblages of a different composition are recorded in siltstone and fine-grained sandstone and show a change in the Psammichnites ichnofacies (Fig. 4). The Psammichnites ichnosp. An ichnoassociation (this term, sensu Gámez Vintaned and Mayoral Alfaro, 1992, is defined in base of the ichnotaxon or ichnotaxa which are recurrently present in a number of ichnoassemblages) and show a variety of fodi-nichnia, pascichnia and horizontal domichnia indicative of enriched, infralittoral substrata under moderate energy conditions (Cruziana ichnofacies). The Psammichnites ichnosp. An ichnoassociation occurs immediately above the last occurrence of stromatolites and coincides with the trilobite and brachiopod expansion (Fig. 4). A very similar set of ichnoassemblages is recorded in fine-grained sandstone and siltstone at the Puente de Hierro section (Lemdadella linareseae biozone, archaeocyath Zone III), with the only difference of the great abundance of Dactylooides cabanasi. This points to substrata even richer than for the upper part of the Arroyo Pedroche I section, under otherwise very similar palaeoecological conditions (Fig. 3). The ubiquity of Dactylooides cabanasi in the lower and middle parts of the Puente de Hierro section permit those ichnoassemblages to be grouped into a Dactylooides ichnoassociation.

Trilobites of the basal levels of the Arroyo de Pedroche I section occur together with other perireefal groups, preserved in calcareous levels. The species Bigotina bivalvata appears above the disappearance of characteristic archaeocyaths of Zone II, preserved in limestones and coinciding with the last record of columnar stromatolites. Trilobites start to abound coinciding with the onset of Psammichnites ichnosp. An ichnoassociation, being preserved mainly in siliciclastic rocks, out of the reefal influence. Soon after, the brachiopod facies (represented here by the genus Paterina) are recorded for the first time in the section.

In summary, low Lower Cambrian (lower Ovetian) rocks from Sierra de Córdoba record a biotic turnover (Pedroche event; Liñán, 2003) which took place at the lower part of the Bigotina bivalvata biozone, a few meters above the disappearance of characteristic archaeocyaths of Zone II, preserved in limestones and coinciding with the last record of columnar stromatolites. At that time, palaeoecological conditions shifted from a shallow, somewhat restricted infralittoral environment (recording archaeocyath, stromatolite and scarce trilobite facies) to a less energetic, probably deeper, infralittoral environment (with archaeocyath, brachiopod and abundant trilobite facies). This, trace and body fossils provide evidences supporting a remarkable palaeoecological disturbance, which was likely to cause the seeming decrease of stromatolite-building communities and the expansion of trilobite, brachiopod and soft-bodied metazoan biotas, in sublittoral (infralittoral) environments. A remarkable palaeoecological shift is also recorded in horizons of similar age at sections in Morocco and Russia hence pointing to a global event, which confirmation will require further studies.
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Limniades, con-


