New ichnological data from the lower Paleozoic of the Central Pyrenees: presence of *Arthrophycus brongniartii* (Harlan, 1832) in the Upper Ordovician Cava Formation

Nuevos datos icnológicos del Paleozoico inferior del Pirineo central: presencia de Arthrophycus brongniartii *(Harlan, 1832) en el Ordovícico Superior de la Formación Cava*

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Abstract: *The ichnogenus* Arthrophycus*, characteristic of Ordovician-Silurian sedimentary rocks, is described by the first time in the Pyrenees. This ichnogenus is located in fine-grained sandstones of the upper part of the Cava Formation, on the Upper Ordovician rocks of the southern slope of the la Rabassa Dome, close to the Andorra-Spain border. Studied samples exhibit characteristics* of the *ichnogenus* Arthrophycus *Hall, 1852, and in particular to the ichnospecies* A. brongniartii *(=*A. linearis*) (Harlan, 1832). Bioturbation structures are well preserved, and diagnostic features of the ichnosubspecies A. brongniartii protrusiva (Seilacher, 2000) can be observed. These data confirm the Ordovician age of the study section, otherwise well-established on the basis of its abundant fossil content.*

Key words: Arthrophycus*, Bioturbation, Ichnology, Ordovician, Pyrenees.*

Resumen: Se describe por primera vez el icnogénero *Arthrophycus* en rocas prevariscas del Pirineo. Este icnogénero, característico del Ordovícico-Silúrico, se ha localizado en areniscas de grano fino de la parte alta de la Formación Cava, en el Ordovícico superior del flanco sur del domo de la Rabassa, cerca de la frontera entre España y Andorra. El buen estado de conservación de las muestras permite precisar que se trata de la icnoespecie *A. brongniartii* (=*A. linearis*) (Harlan, 1832) y más concretamente de la icnosubespecie *A. brongniartii protrusiva* (Seilacher, 2000). Estos datos confirman la edad ordovícica de la serie, por otra parte bien establecida en base al abundante registro fósil que contiene.

Palabras clave: *Arthrophycus*, Bioturbación, Icnología, Ordovícico, Pirineo.

INTRODUCTION

In the Pyrenees a complete pre-Variscan succession, ranging in age from late Neoproterozoic to middle Carboniferous, can be recognized (Fig. 1). Late Neoproterozoic to Early Ordovician rocks constitutes a thick (3,000 m) succession of metasedimentary rocks with gneissic bodies and layers of marbles, quartzites and calc-silicates interbedded in its lower part. A well-dated Upper Ordovician succession (based on brachiopods, bryozoans, cystoids, corals, and trilobites; see Cavet, 1957 and Hartevelt, 1970) lies unconformably over the former sequence (Casas and Fernández, 2007).

Although it is difficult to evaluate the magnitude of this unconformity, it can be assumed that there was considerable erosion before the Upper Ordovician deposition because Upper Ordovician rocks overlie different sections of the pre-Upper Ordovician succession in the Central and Eastern Pyrenees. Although the age of the Upper Ordovician succession is well known, little attention has been paid to ichnofossils. In this work we present new data about the presence of trace fossils on the Upper Ordovician rocks of the Central Pyrenees.

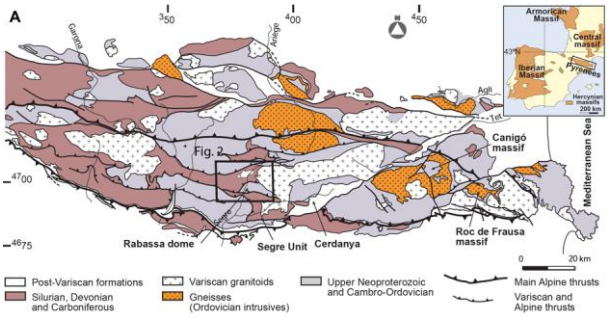

FIGURE 1. *Simplified geological map of the Central and Eastern Pyrenees with the location of the study area (After Casas y Fernández, 2007).*

GEOLOGICAL SETTING AND SAMPLES

Samples were collected near the Andorra-Spain border, on the southern slope of the La Rabassa Dome

(Fig. 2). In this area, the Upper Ordovician rocks constitute a low grade metamorphosed fining-upwards sequence with marked variations in thickness (100–1000 m).

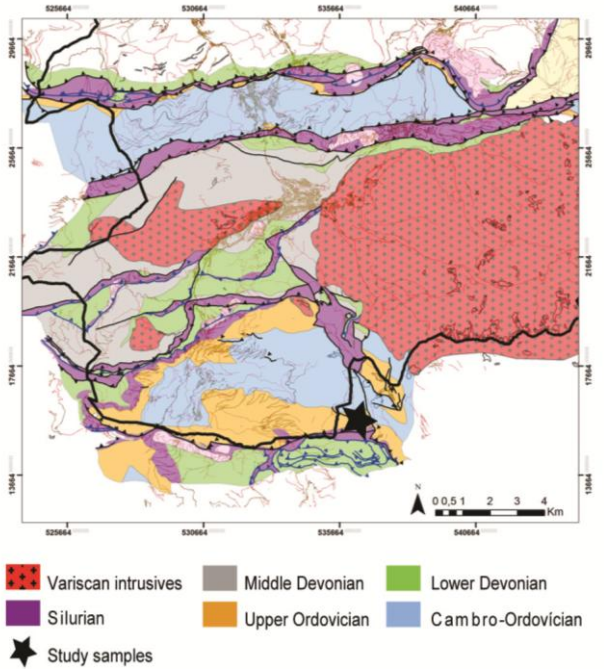

FIGURE 2. *Geological map of southern Andorra with the location of the studied samples (After Margalef, 2015).*

Hartevelt (1970) defined five main siliciclastic formations (Fig. 3) in this area. From base to top: A) The Rabassa Conglomerate Formation is made up of red–purple, unfossiliferous conglomerates and sandstones that form discontinuous lenses ranging in thickness from a few metres to 200 m. Subrounded to well-rounded clasts of slate, quartzite and quartz-veins reach up to 50 cm in diameter. The Rabassa conglomerates, attributed by Hartevelt (1970) to a Sandbian age, are conformably overlain by the Cava Formation. B) The Cava Formation, ranging in thickness from 100 to 800 m, consists of feldspathic sandstones (predominant in the lower part of this formation), overlain by shales, siltstones and fine-grained sandstones, typically green or purple in color in their upper parts. Brachiopods and bryozoans are locally abundant and allow attributing a Caradoc-Ashgill transition age (Katian) to this formation. C) The Estana Formation lies above the Cava Formation and consists of limestones and marly limestones, up to 10 meters in thickness, which constitutes a good stratigraphic key level, the "schistes troués" or "Grauwacke à Orthis" and the "Caradoc limestones" of French and Dutch geologists. Conodonts and brachiopoda are abundants, yielding a Middle Ashgillian (Katian) age. D) The Ansovell Formation consists of monotonous, black and grey slates, with very few sandstone lenses, that reach a thickness of 40–50 meters in the Rabassa Dome. This formation is overlain by the Bar Quartzite Formation. E) The Bar Quartzite Formation consists of dark-grey, medium-rounded grained quartzites with ripples in its upper part. Although Hartevelt (1970) proposed an Ashgillian age for the Ansovell and Bar formations, some authors suggest that the Ordovician-Silurian boundary can be located within the Bar quartzite. Samples were collected in the upper part of the Cava Formation, in purple fine-grained sandstones (Fig. 3).

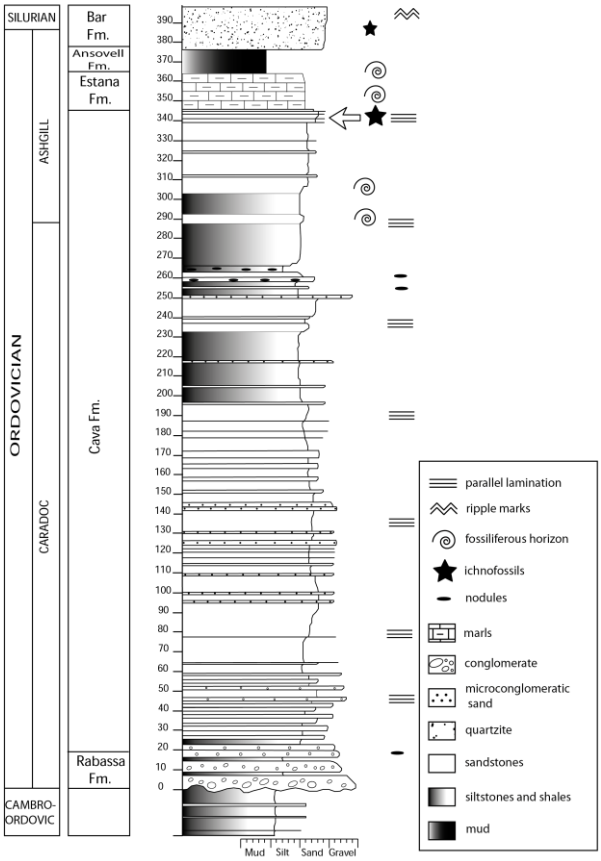

FIGURE 3. *Synthetic stratigraphic column of the pre-Silurian rocks of the Rabassa dome with the location of the studied samples.*

DESCRIPTIVE ICHNOLOGY

Ordovician trace fossils aims of this study have been identified as arthrophycid burrows (Fig. 4). Ichnofamily Arthrophycidae (or 'Arthrophycids') was erected by Seilacher (2000) to designate "Paleozoic worm burrows characterized: a) by regular transverse ridges, which are often discontinuous, giving the casts a squarish cross section; and b) by teichichnoid backfill structures (*spreiten*) resulting from transverse or oblique dislocation of a J-shaped tunnel through the sediment. Depending on the behavioral programs, the backfill structures may have linear, palmate, fan-shaped, spiral, or multi-winged geometries. Also, their internal structures may be either protrusive or retrusive.", and included the ichnogenera *Arthrophycus*, *Daedalus* and *Phycodes* within this new ichnofamily; with *Arthropycus* as typical ichnogenus.

Thereafter, Rindsberg and Martin (2003) emended the diagnosis of this ichnofamily as "burrows with vertical to horizontal *spreite* resulting from regular, oblique backfill

generally having a flattish floor and transverse sculpture; striae common; burrows of limited to indefinite length, simple or branched, straight or curved, in some cases composed of segments arranged angularly."

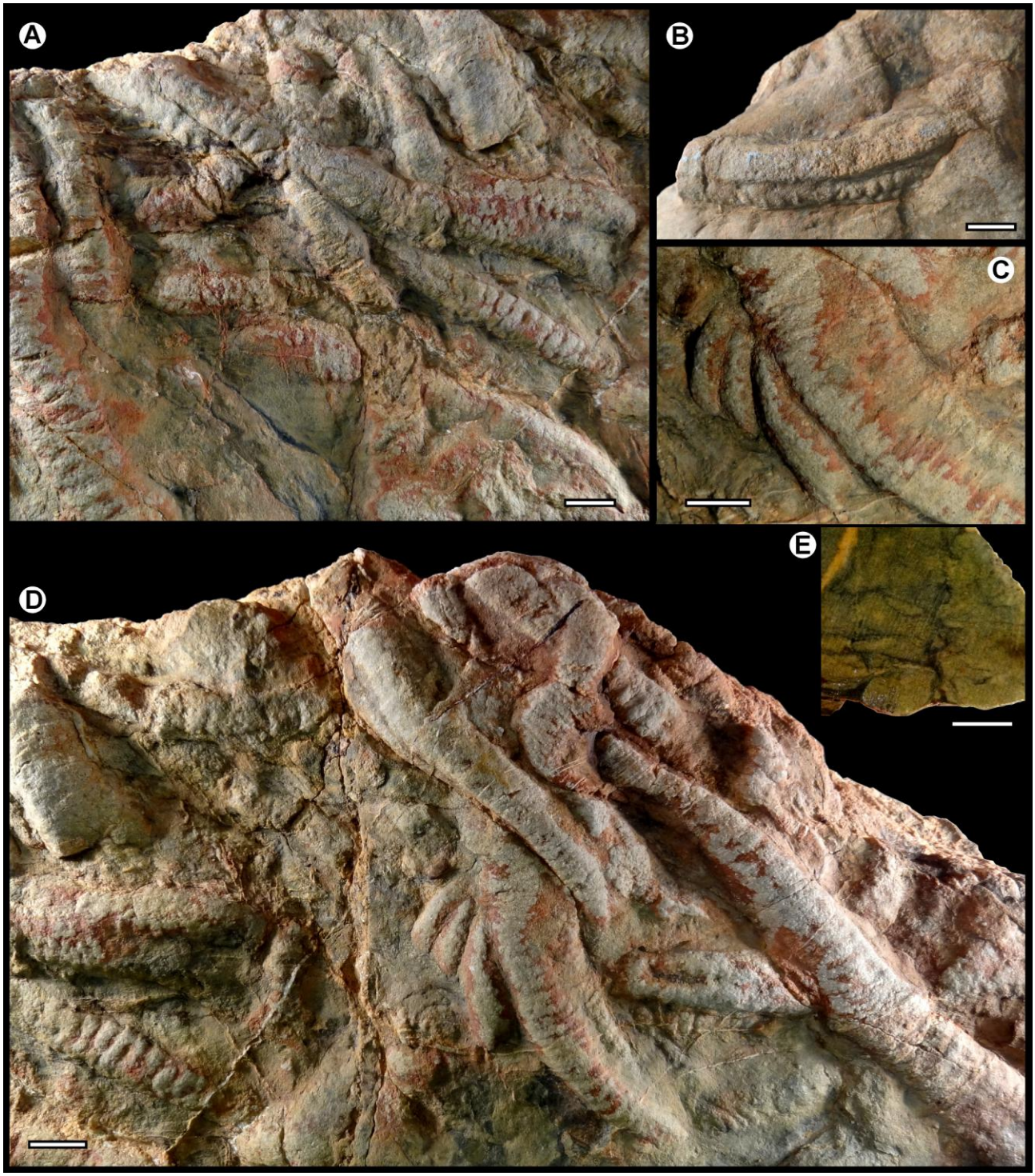

FIGURE 4. Arthrophycus brongniartii. *A & D) Several specimens showing the typical annulated ornamentation and different crosscutting relationships. B) Specimen exhibiting annulated arrangement and a longitudinal median groove. C) Detail of a fan-like arrangement of burrows (possible transition to* A. alleghaniensis*). E) Cross-section showing a vertical protrusive* spreite *with the main tunnel in the lower part. (Scale bars=1 cm; all pictures correspond to parallel sections to the bedding (hyporeliefs), except Fig. 3E).*

In particular, the bioturbation structures from the study area are linear-to-slightly-curved, unbranched and horizontal-to-subhorizontal burrows, parallel to the bedding and preserved as hyporeliefs (Fig. 4A, D). They exhibit an annulated arrangement (Fig. 4A-D), a squarish cross-section (up to 14 mm in diameter; Fig. 4E) and a longitudinal median groove (Fig. 4B). Once, a fan-like pattern is also observable (Fig. 4C). Although the studied traces occur in an intensely burrowed horizon (40 mm thick), a protrusive *spreite* can be occasionally preserved

(Fig. 4E). The traces were studied in natural exposures, which are mostly parallel to bedding. In order to carry out a detailed analysis of burrow geometry and morphology, several cross cuts were obtained from one of the samples.

All these architectural features are characteristic of the ichnogenus *Arthrophycus* Hall, 1852, and in particular to the ichnospecies *A. brongniartii* (=*A. linearis*) (Harlan, 1832). In addition, the presence of the protrusive *spreite* allows being more accurate with its ichnotaxonomic assignation, since this is a diagnostic feature of the ichnosubspecies *A. brongniartii protrusiva* (Seilacher, 2000).

With respect to the *Arthrophycus* tracemaker, worms and arthropods have been proposed as possible candidates (e.g. Seilacher, 2000, 2007; Rindsberg and Martin, 2003; Mángano et al., 2005). The hypothesis of a 'worm' producer (vermiform organism) is mainly based on a) the length and continuity of the structure, b) the presence of delicate bioglyphs interpreted as produced by wrinkles of a flexible cuticle, and c) the regular annulation as a result of peristaltic or hydrostatic movements of a vermiform producer (e.g. Seilacher, 2000; Mángano et al., 2005 and references therein). By contrast, an arthropod authorship is defended by a) the presence of 'chevrons' or zipper-like annulations attributed to appendage marks (see Mángano et al., 2005 and references therein), b) Silurian specimens with uncommon features for classic *Arthrophycus* (Rindsberg and Martin, 2003), and c) the occurrence of a unique long-bodied arthropod (*Pleuralata spinosa*) in stratigraphic proximity with *A. alleghaniensis* (see McCoy et al., 2012). In any case, the assignation of *Arthrophycus* as a feeding trace (fodinichnion) seems to be clear.

In addition, the importance of ichnofamily Arthropycidae also lies in its ichnostratigraphic significance, since in absence of index fossils or '*Cruziana* stratigraphy', it can be useful as alternative to date lower Paleozoic sedimentary rocks. In particular, the ichnogenus *Arthrophycus* is characteristic of Ordovician-Silurian rocks. Five ichnospecies have been described: *A. minimus* (Upper Cambrian (Furongian)/Lower Ordovician); *A. brongniartii* (Lower Ordovicain/Lower Silurian); *A. alleghaniensis* (Lower Silurian), *A. lateralis* (Lower Silurian); and *A. parallelus* (Carboniferous) (see Buatois and Mángano, 2011). In our particular case, the presence of *A. brongniartii* in the Cava Formation confirms its Upper Ordovician age, previously obtained from the fossil content (brachiopods and bryozoans).

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