

Small shelly fossils from the Lower Cambrian Lastours Formation, southern Montagne Noire, France

Microfossiles à paroi squelettique de la Formation de Lastours (Cambrien inférieur) en Montagne Noire méridionale, France

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Abstract

The paper presents the first description and illustration of archaeocyaths and small shelly fossils from the lower member of the Lower Cambrian Lastours Formation (southern Montagne Noire). The outcrops of the Caunes–Minervois sheet thrust (Pardailhan nappe) represent alternation of relatively low-energy, shallow subtidal substrates (highly bioturbated mottled limestones), and reef flanks or inter-reef settings surrounded by winnowed archaeocyath-spiculate shelly pavements. The archaeocyathan assemblage (Botoman in age) is dominated by the genera *Anthomorpha* and *Inessocyathus*, from which the species *Inessocyathus levis* is reported for the first time in the southern Montagne Noire. Phosphate-shell microfossils comprise hyolithelminths (*Hyolithellus* and *Torelrella*) and conodont-related sclerites (*Yunnanodus*), the latter having previously only been reported from the Meishucunian of south China. © 2002 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

Résumé

Ce travail présente la première description et illustration d'archéocyathes et de microfossiles à paroi squelettique du membre inférieur de la Formation de Lastours (Cambrien inférieur de la Montagne Noire méridionale). Les affleurements de l'échelle tectonique de Caunes–Minervois (nappe de Pardailhan) montrent une alternance de dépôts marins peu profonds à basse énergie (fortement bioturbés donnant un aspect de calcaires « mouchetés »), et de flancs récifaux ou de domaines inter-récifaux entourés de lumachelles à archéocyathes et spicules transportés. L'assemblage d'archéocyathes (d'âge Botomen) est dominé par les genres *Anthomorpha* et *Inessocyathus* ; il comprend l'espèce *Inessocyathus levis*, citée pour la première fois en Montagne Noire méridionale. Les microfossiles à paroi phosphatée sont représentés par des hyolithelminthidés (*Hyolithellus* et *Torelrella*) et des sclérites conodontiformes (*Yunnanodus*), ces derniers cités jusqu'à présent uniquement dans le Meishucunien de la Chine méridionale. © 2002 Éditions scientifiques et médicales Elsevier SAS. Tous droits réservés.

Keywords: Small shelly fossils; Archaeocyaths; Carbonates; Lower Cambrian; Montagne Noire; France

Mots clés: Microfossiles; Archéocyathes; Carbonates; Cambrien inférieur; Montagne Noire; France

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1. Introduction

The Lower Cambrian strata of the Montagne Noire (southern France) have been classically the focus of studies on the early radiation of metazoans and the environments in which the “Cambrian explosion” occurred. Since the discovery of archaeocyaths (Bergeron, 1894), these rocks have contributed to the understanding of the Lower Cambrian fauna through studies on archaeocyaths (Debrenne, 1964), trilobites (Cobbold, 1931, 1935; Courtessole et al., 1971; Courtessole and Jago, 1980; Geyer, 1992; Álvaro et al., 1998b), brachiopods (Termier and Termier, 1974), chanceloriids (Geyer, 1986) and ichnofossils (Álvaro and Vizcaino, 1999). However, although local zonations have been established (last revision in Álvaro et al., 2001), convincing inter-regional correlations remain difficult due to the rare and scattered occurrence of biostratigraphically significant fossils. This is mostly controlled by a high degree of recrystallization and selective dolomitization of carbonates, and severe tectonic deformations leading to diverse kind of fossil preservation related to the original texture and mineralogy of skeletal remains: e.g. the micritic skeletons of archaeocyaths rarely reproduce their original texture due to neomorphic replacement and mechanical stress inducing stretched and folded frameworks on larger skeletons, contrasting with the micritized outlines on small and/or mid-sized cups. As a result, specific and even generic determinations are frequently impossible.

The purpose of this paper is to characterize, for the first time, the fossil record of the lower member of the Lastours Formation, in order to improve the paleoecological and biostratigraphic knowledge of Lower Cambrian carbonate strata preserved in the southern Montagne Noire. Due to the recrystallized nature of these limestones, the analysis is approached in two ways: selected archaeocyathan-rich samples were determined using polished slabs and thin sections, whereas phosphate-shell microfossils were released by acid digestion. Our study of this newly discovered macro- and microfossil assemblage is a contribution toward the larger purpose of elucidating the biodiversity of the Lower Cambrian, microbial–archaeocyathan reef complexes that colonized the western Gondwana margin.

2. Geological setting, stratigraphy and facies

The lower member of the Lastours Formation (sensu Álvaro et al., 1998a) is exposed in discontinuous, somewhat faulted bands throughout the Pardailhan nappe. This member consists of massive to bedded, white, grey and black limestones (locally dolomitized) lacking shaly intercalations. The last character permits differentiation of this member from the underlying Pardailhan Formation and the upper members of the Lastours Formation.

The pond studied in this work is located approximately 2.5 km eastwards of the village of Caunes–Minervois

(Fig. 1), on the Pardailhan nappe. It was reported by Debrenne (1964, Fig. 13) under the name « Notre-Dame du Cros » ($x = 617$, $y = 113.8$ in Berger et al., 1993), where scarce, highly broken and badly preserved archaeocyathan cups were then observed but not described. The outcrop is located in one of the thrust sheets that characterize the southwesternmost edge of the nappe, bounded by Tertiary sediments. In fact, this small thrust sheet was first reported as Tertiary limestones in the first edition of the geological map (Thoral et al., 1951), and definitively assigned to Cambrian rocks in the second one (Berger et al., 1993). The ravines associated with the pond provide a reliable section, up to 30 m thick, of the lower member of the Lastours Formation (Fig. 2). Major lithostratigraphic boundaries are not exposed, and the top of the limestone has yielded an abundant and determinable fossil record composed of archaeocyaths and phosphatic microfossils.

In the area investigated, the limestone outcrops can be subdivided into five subunits (I to V), whose lithologic and petrographic characters are summarized in Table 1. The subunits I, III and V are highly recrystallized, and their original microfacies difficult to recognize. Calcareous skeletons (such as archaeocyaths, trilobites and echinoderm ossicles) are commonly preserved as spar-filled moulds of blocky calcite cements (50–200 μm across). In some cases, the sparry mosaics do not mimic any bioclast shape, but display more irregular outlines that cannot be attributed to any specific taxon. The matrix is heterogeneously recrystallized to microsparite.

Although all the subunits are partially bioturbated, the subunit II exhibits a dominant burrow-mottled aspect. The fine- to medium-crystalline limestone, variably to completely burrow-mottled, is nearly unfossiliferous and originally dominantly micritic. Patches of orange-colored ferroan dolomite (composed of subelliptical sucrosic mosaics of euhedral dolomite rhombs, up to 300 μm across) form a network of irregular thin nodular interbeds. Locally, bioturbation is so pervasive that bedding is lost.

Finally, subunit IV (on which this work is focused) consists of microbial boundstones and archaeocyathan–microbial floatstones. Its bottom is marked by a sharp decrease in the amount of bioturbation with concomitant preservation of physical sedimentary structures. The abundant fossil content of the subunit (comprising archaeocyaths, calcisponge spicules, trilobites, echinoderm ossicles, brachiopods, hyoliths, phosphatic small shelly fossils, etc.) forms a shell coquina in a limestone matrix. Fossils are commonly visible in low relief on outcrop surfaces, after weathering out of the matrix. Skeletons are not aligned in any distinct direction, reflecting an apparent random embedding pattern of the bioclasts. Archaeocyaths are preserved lying parallel to bedding and not in life position. The poorly sorted, abraded skeletons suggest that the fossils were reworked and transported a short distance. Some skeletons are infilled with micritic matrix, commonly forming geopetal fabrics paralleling stratification. The most common sediment is

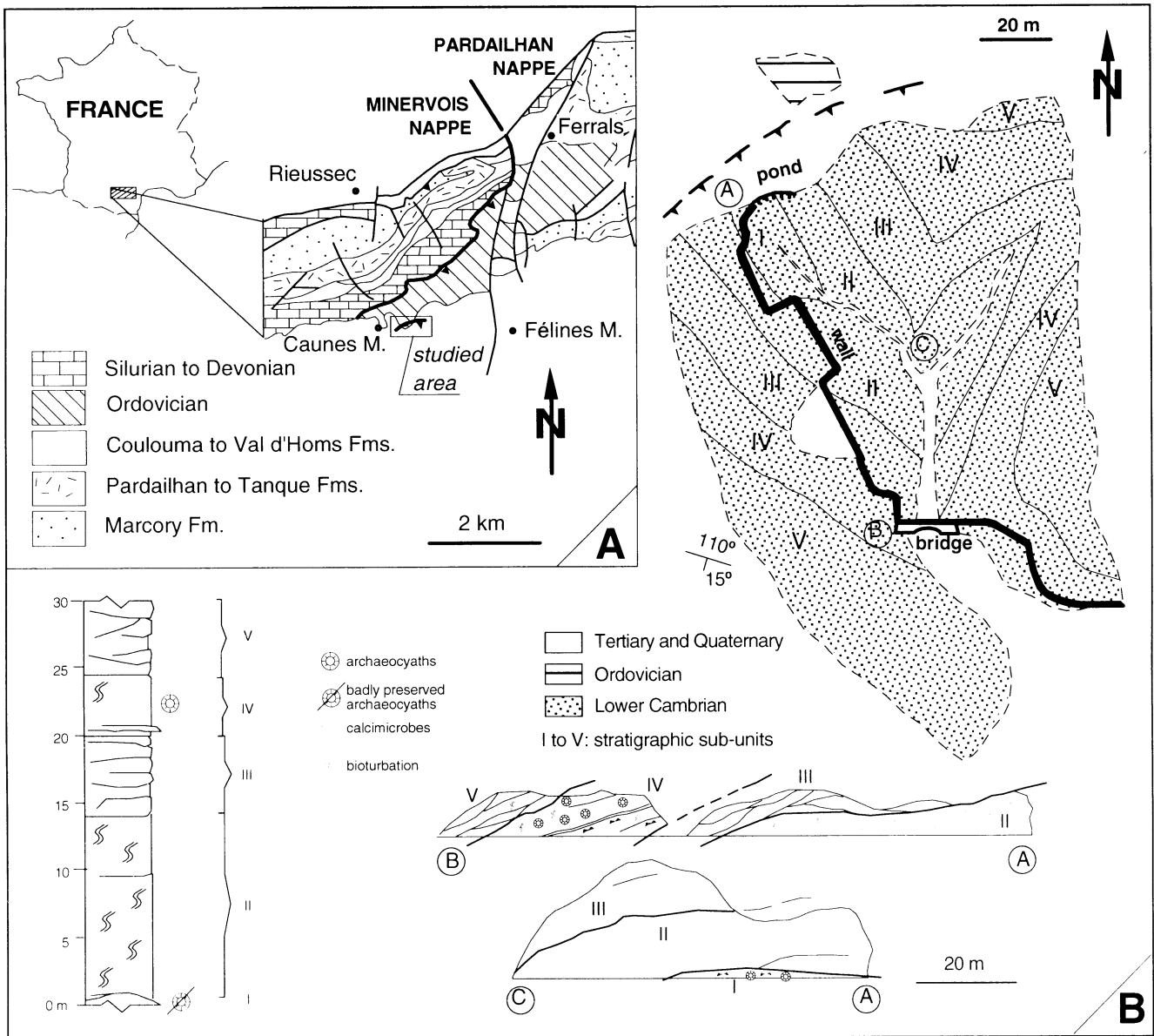


Fig. 1. (A) Geological sketch map of the Caunes–Minervois thrust sheet at the contact between the Minervois and Pardailhan nappes in the southern Montagne Noire. (B) Map of the Caunes–Minervois thrust sheet, geological sections and stratigraphic log.

Fig. 1. (A) Schéma géologique de l'écaïlle tectonique de Caunes–Minervois sur le contact entre les nappes du Minervois et de Pardailhan en Montagne Noire méridionale. (B) Carte de l'écaïlle tectonique de Caunes–Minervois, sections géologiques et coupe stratigraphique.

micrite and fine silt-size skeletal debris with numerous calcisponge spicules and calcareous microspheres of uncertain affinity. The spicules are composed of optically single crystals of calcite, and both monoaxon and polyaxon in shape, suggesting provenance from vanished sponges, originally very abundant. The subunit contains the most abundant and diverse fauna of determinable archaeocyaths, including the following taxa: *Inessocyathus levis* DEBRENNE, 1964, *?Afiacyathus* sp., *Carinacyathidae* gen. et sp. indet, *Erismacoscinina* gen. et sp. indet, *Erismacoscinus* cf. *elongatus* (BORNEMANN, 1886), *Erismacoscinus* cf. *calathus* (BORNEMANN, 1886), *Protopharetra stipata* DEBRENNE, 1964, *?Chouberticyathus* sp., *Dictyocyathus*

cf. *verticillus* (BORNEMANN, 1891), *Anthomorpha margarita* BORNEMANN, 1886 and *Anthomorpha immanis* DEBRENNE, 1964 (Fig. 3). Archaeocyath content varies from 10% to 40%. Two types of micrite occur as background matrix: (i) a microbioclastic spiculite, with scattered intraclasts, and disarticulated and broken trilobites and brachiopods; and (ii) a mottled micrite composed of unidentified thromboids replaced by microsparite and sparry masses of lighter colored micrite; the latter does not display any direct evidence of the former presence of calcimicrobes at the microscopic level, but shows characteristic clotted and branching morphologies at centimetric and decimetric scale, displaying decimetre-scale microbial patch reefs.

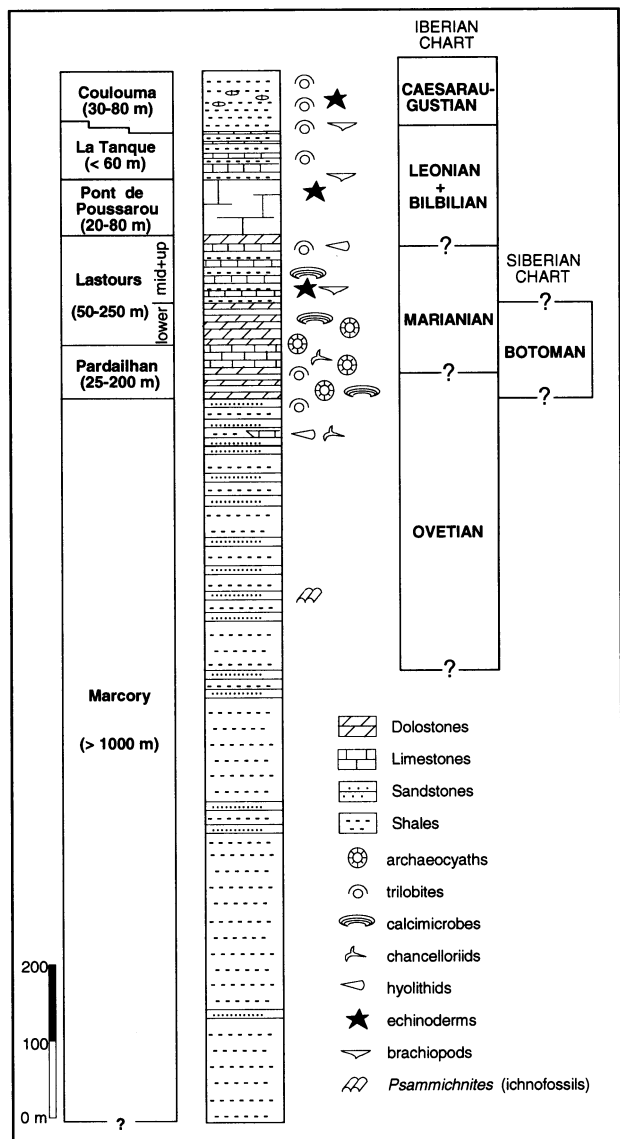


Fig. 2. Lower and lowermost Middle Cambrian stratigraphic units of the southern Montagne Noire, based on Álvaro et al. (1998a), Álvaro and Vizcaíno (1999), and this work.

Fig. 2. Unités stratigraphiques du Cambrien inférieur et moyen (d'après Álvaro et al. 1998a; Álvaro et Vizcaíno 1999, et ce travail).

3. Systematic paleontology of the small shelly fossils

Illustrated fossil specimens, polished slabs and thin sections are housed in the Muséum national d'Histoire naturelle of Paris (Laboratoire de Paléontologie; acronyms MNHN and R). Phosphatic microfossils were extracted from the limestone matrix by dissolving the rock in a dilute (10% by volume) acetic acid solution. The acid-resistant skeletons were manually picked from the residues.

Phylum and Class uncertain

Order Hyolithelminthes FISCHER, 1962

Remarks: This order, widely accepted as worm tubes, is characterized by small conical phosphatic tubes with an irregular curved apical area, elongate and straighter toward

the aperture. Their cross-section can be circular (Hyolithellidae Walcott, 1886) or elliptical (Torellellidae Holm, 1893). The outer surface of the tubes may be ornamented by distinct striae or ribs, whereas their inner surfaces seem to be smooth. In contrast to the original description by Billings (1871) and the original diagnosis of the order by Fisher (1962), hyolithelminths lacked mineralized operculum (Bengtson et al., 1990).

The subdivision of hyolithelminths into two families was established more than a century ago, and is only based on few morphological features: the distinction between hyolithellids and torelellids is mostly based on cross-sections. The existence of keels and pronounced striae in Torellellidae is not obligatory. Consequently, the diagnostic basis for both families is rather imprecise, mainly studying microfossils from highly deformed strata. This problem persists and intensifies the ambiguities between numerous definitions of genera and species (for a discussion see Landing, 1988; Brasier, 1986, in Cowie and Brasier, 1989: 127). Further research and discussions are necessary to clarify if the diagnostic characters between species are really justifiable, which is beyond the scope of this paper.

Family Torellellidae HOLM, 1893

Genus *Torellella* HOLM, 1893

Type species: *Torellella laevigata* (LINNARSSON, 1871).

Diagnosis: Small, narrow, conical, calcium-phosphatic tube, curved and irregularly shaped near the closed apex and straighten toward aperture; low angle of wall divergence; elliptical to biconvex (lens-shaped) cross-section; aperture perpendicular to shell axis; exterior surface with transverse striae and ribbing more pronounced than in the hyolithellids; inner surface smooth.

Torellella mutila MISSARZHEVSKY, 1989

Fig. 4(1–4)

1989 *Torellella mutila* nov. sp. (Missarzhevski, 1989, p. 195; pl. 24, Fig. 8).

1994 *Torellella mutila* (Elicki, 1994, p. 77; pl. 7, Fig. 11).

Diagnosis: Species of *Torellella*, straight and narrow, displaying a low rate of wall divergence and two keels at the aperture section.

Description: Elongated, narrow, hollow, phosphatic tube fragments bearing elliptical cross-sections. One specimen (Fig. 4(1–2)) shows two indistinctly developed keels on the tapered parts of the cross-section. The narrowest and proximal part of the tube is strongly curved, and in all specimens irregular depending on growth stages. The tubes, with diameter up to 270 µm, show a variable wall-thickness between 5 and 10 µm. No different shell-layers are visible. The rate of ellipticity increases gradually and the angle of divergence is low (less than 20°), and mostly constant, so that the tubes are more flattened on their elongated straight (distal) part. Preservation is incomplete, so that only some areas display simple and more or less regular ring-like

Table 1
Characteristics of facies comprising the lower member of the Lastours Formation on the Caunes–Minervois thrust sheet; M, mudstone; W, wackestone; P, packstone; B, boundstone; F, floatstone

Tableau 1

Caractéristiques principales des faciès reconnues dans le membre inférieur de la Formation de Lastours (écaïlle tectonique de Caunes–Minervois); M, mudstone; W, wackestone; P, packstone; B, boundstone; F, floatstone

	Sub-units	Composition	Physical structures	Biogenic structures	Skeletal components
I	Archaeocyathan-microbial lenses	dark grey to black, medium-bedded to lenticular, archaeocyathan-Microbial F and W Locally bioturbated	distinct, dm-thick lenticular geometries	dispersed burrows	highly recrystallized fabric
II	Burrow-mottled micritic limestones irregularly dolomitized	light to medium grey, thick-bedded to massive, weakly stylo-nodular, M to W	bedded	burrows filled with discrete sucrosic	none
III	Lenticular, fossil-poor limestones	light to medium grey, lenticular, fossil-poor M to W	nodular patterns lenticular geometries	slightly bioturbated	scarce and small fragments of undetermined biolcasts
IV	Burrow-mottled microbial Limestones	light to medium grey thick-bedded to massive, archaeocyathan f interbedded with microbial-Dominant B and cm-thick P	dm-thick bedded strata with erosive storm-induced bioclastic coquinas	highly bioturbated	<i>Ephiphyton</i> -like thromboids, archaeocyaths, brachiopods, calcisponge spicules, phosphatic microfossils, echinoderms, etc.
V	Lenticular, Fossil-poor Limestones	light to medium grey, thin-bedded to lenticular, M to W	nodular patterns due to mica-rich stylo-nodular fabric	slightly bioturbated	archaeocyaths, calcumicrobes, etc.

structures (Fig. 4(1)), and some weak growth lines on the straight part of the outer surface (Fig. 4(1,3–4)). The distance between the rings can reach 40 µm depending on their position on the tube. The inner surface is smooth.

Discussion: The general growth patterns, type of curvature and cross-section of the specimens indicate its affiliation to the genus *Torelrella* HOLM, 1893 (in Fisher, 1962). The specimens show morphological features shared by several species. Strong similarities exist with *T. mutila* MISSARZHEVSKY, 1989 and *T. lentiformis* (SYSOIEV, 1962): both species apparently differ only in the lower and rather continuous rate of wall divergence in *T. mutila* (so that this tube is straighter and narrower), and in the occurrence of keels. Although their value as a diagnostic tool is questionable, the specimens are assigned to *T. mutila* on the basis of the morphological features described above.

Occurrence: *Torelrella mutila* is known from the early Botoman of Siberia and Mongolia (Missarzhevsky, 1989), and the middle–late Marianian of Germany (immediately overlying the *Ferralsia saxonica*-bearing layer; Elicki, 1994).

Torelrella lentiformis (SYSOIEV, 1962)

Fig. 4(5–8)

1962 *Lentitheca lentiformis* nov. sp. (Sysoiev, 1962, pl. 1, Fig. 1).

1963 *Lentitheca lentiformis* (Sysoiev, 1963, pl. 49, Fig. 1a).

1969 *Torelrella lentiformis* (Rožanov et al., 1969, pl. 8, Fig. 2).

1974 *Torelrella lentiformis* (Meshkova, 1974, pl. 19, Fig. 1).

1982 *Torelrella lentiformis* (Rožanov et al., 1982, p. 57, pl. 5, Figs. 6–7).

1983 *Torelrella lentiformis* (Sokolov and Zhuravleva, 1983, pl. 60, Fig. 9).

1986 *Torelrella lentiformis* (Brasier, 1986, pl. 9, Figs. 1–r).

1989 *Torelrella lentiformis* (Missarzhevski, 1989, pl. 24, Fig. 6).

1989 *Torelrella lentiformis* (Cowie and Brasier, 1989, pl. 7.1, Fig. 13).

1994 *Torelrella lentiformis* (Elicki, 1994, p. 78; pl. 7, Figs. 9–10).

Diagnosis: Species of *Torelrella* irregular and curved in shape; angle of wall divergence variable, increased sharply near the proximal part.

Description: Small phosphatic, elongated, tube fragments of narrow shape and elliptical cross-section. Keels are not developed. Nearly all tubes show a distinct irregular and curved tube shape, both laterally and dorsoventrally. The thickness of the tube walls ranges from 5 to 10 µm. No different shell-layers are visible. The angle of divergence is not constant and increases sharply near the narrowest (proximal) part of the tube. The largest (distal) part of each tube is clearly more elliptical in section, as in *T. mutila*. Most specimens display growth lines, well preserved on outer surfaces: these structures are regular (e.g. on Fig. 4(6)) or irregular (Fig. 4(8)), and depend on the relative position (juvenile vs. adult). Ring-like or other ornamentation characters are not observed on outer walls. The inner surfaces of these hollow tubes are smooth.

Discussion: As in the case of *T. mutila*, the material, growth and curvature patterns, and cross-sections indicate the affiliation to the genus *Torellella*.

Occurrence: *T. lentiformis* is known from the Tommotian of Siberia (Rozanov and Sokolov, 1984), the Tommotian levels of Nuneaton (Brasier, in Cowie and Brasier, 1989), and occurs in Germany overlying lower–middle Ovetian archaeocyath-bearing carbonates (Elicki, 1994). In addition, the species is known from Tommotian–Botoman strata of Mongolia (Rozanov, 1982), and probably from Massachusetts and Shropshire (Brasier, in Cowie and Brasier, 1989).

Torellella sp. indet,

Fig. 4(9)

Discussion: This specimen fits with the hitherto described *Torellella* species in its main tube characteristics. Hence, the general tube growth pattern, the characteristic cross-section, and also the tube material is the same. The degree of divergence is low compared to tube length. The fossil remain shows a rather long part of the tube with a more or less circular cross-section. Only at the distal “end” of the preserved fragment a distinct increase of the angle of divergence, as well as a change from relatively circular to elliptical cross-section and a change in direction is present. The preservation, however, is poor and incomplete, and no further details can be seen. The mentioned main features of the tube indicate that the fossil fragment belongs to the genus *Torellella*. Neither growth lines, rings nor ridge structures are observed because of the poor preservation. Regarding the taxonomic uncertainties of this group, the specimen is described in open nomenclature.

Family Hyolithelidae WALCOTT, 1886

Genus *Hyolithellus* BILLINGS, 1871

Type species: *Hyolithellus micans* (BILLINGS, 1871).

Diagnosis: Small, narrow, conical, calcium–phosphatic tube, curved and irregular near the closed apex and straighten toward the aperture; low angle of wall divergence; circular cross-section; shell composed of thin laminae that thicken progressively toward the aperture; the latter perpendicular to shell axis; exterior surface sometimes covered by small transverse ridgelets and striae, inner surface smooth.

Remarks: In the original diagnosis an “operculum” was included that was later identified as a fossil remain of another organism (Bengtson et al., 1990). Several uncertainties need to be addressed: the specific affinity of this genus is taxonomically very problematic by comparison with the other Hyolithelmites group (*Torellella*). The poor preservation of the observed specimens does not allow classification at the species level. Distinct thickness variation is not useful as a diagnostic character.

Hyolithellus sp. indet,

Fig. 5(1–3).

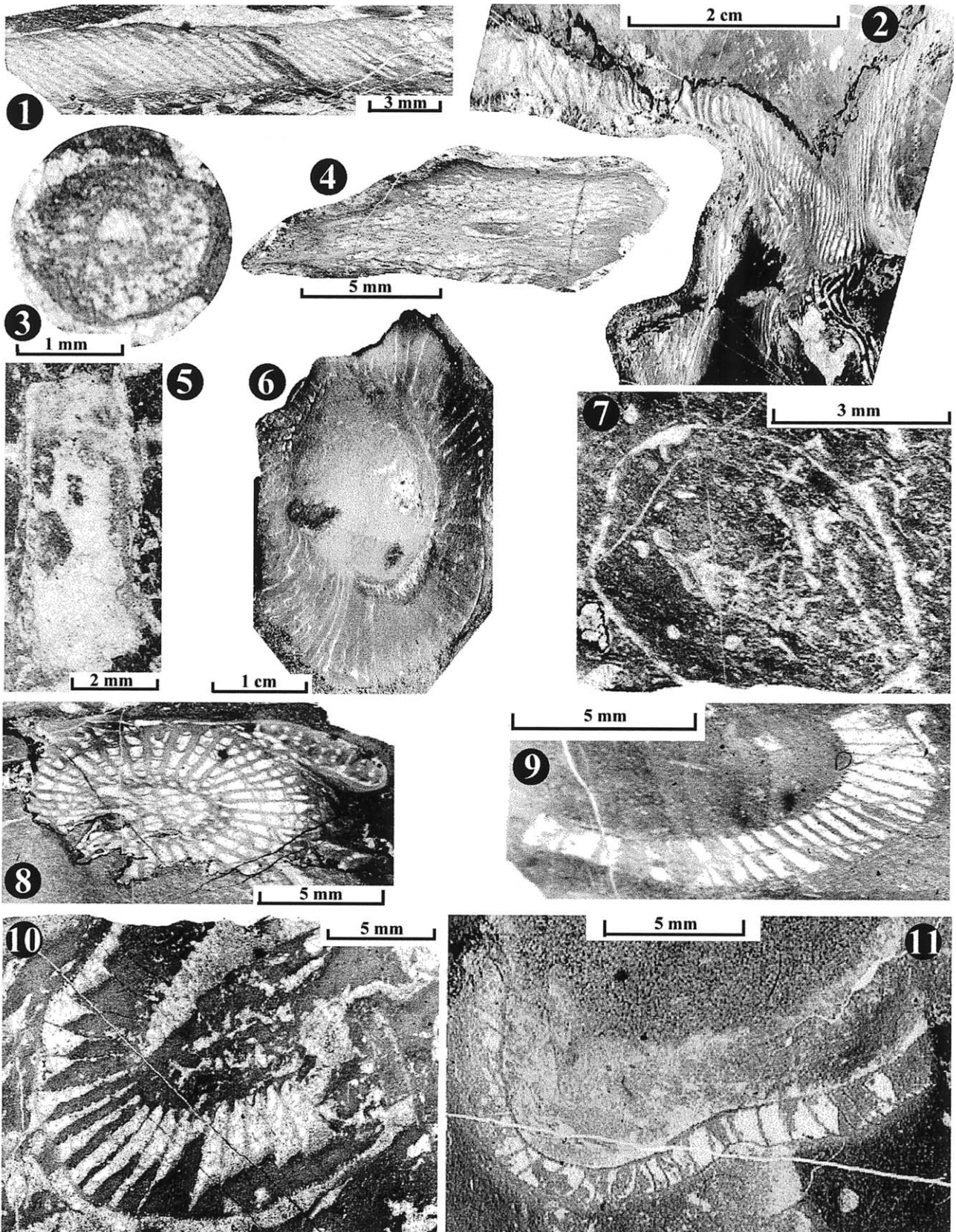
Description: Narrow, curved, phosphatic tube fragments with a circular cross-section. The curved (proximal) part occupies a significant part of the total length. The angle of divergence is low and constant. Preservation is poor, but some more or less regular ridges are visible on the outer surface (Fig. 5(1,2)); the distance between these structures is around 15 µm. An increase in ridge separation on the “proximal” part may be present. Other ornamental characters are not observed. The inner surface is generally smooth. The maximum diameter of the tube fragments is about 200 µm. The wall-thickness is irregular and ranges from 14 to 20 µm in the same level of the tube (Fig. 5(2)). The tube wall of the specimens seems to be three-layered (Fig. 5(3)): the poor and only locally preserved inner and outer layers are less than 7 µm thick, whereas the middle (main) layer is 11–18 µm thick. None of the layers show any distinct internal pattern (sublayering, crystal orientation, etc.).

Discussion: Because of the tube composition, the circular cross-section and the general shape, the described specimens are assigned to the genus *Hyolithellus*.

Occurrence: *Hyolithellus* display a wide paleogeographic distribution (Siberia, Mongolia, India, North and South America, Australia, Antarctica, Europe) in Lower to

Fig. 3. Archaeocyaths of the Caunes–Minervois thrust sheet. (1) *Anthomorpha margarita* BORNEMANN; longitudinal section of an intervallum fragment, MNHN M84265 (AL 15a.2). (2) *Anthomorpha immanis* DEBRENNE; longitudinal section with exocyathoid outgrowths at the base, MNHN M84266 (AL CMO). (3) *Protropharetra stipata* DEBRENNE; transverse section of a young cup, MNHN M84261 (AL 2.2). (4) *Dictyocyathus* cf. *verticillus* (BORNEMANN); stretched transversal cup, MNHN M84263 (AL 15a.1). (5) Carinacyathidae gen et sp. indet; longitudinal section showing the S-shaped, outer wall with non-communicating canals, MNHN M84268 (AL 15c.2). (6) ?*Afiacyathus* sp.; rare synapticalae, MNHN M84267 (AL 1). (7) ?*Chouberticyathus* sp.; transverse section of a skeleton replaced by sparry calcite, surrounded by sponge spicules (AL 15b). (8) *Anthomorpha margarita* BORNEMANN; transverse basal section with vesicular tabulae, MNHN M84264 (AL 2). (9) *Erismacoscinus* cf. *elongatus* (BORNEMANN); oblique longitudinal section, MNHN M84259 (AL 6). (10) *Inessocyathus levis* DEBRENNE; oblique longitudinal section, MNHN M84258 (AL 1a). (11) *Erismacoscinus* cf. *calathus* (BORNEMANN); longitudinal section of an intervallum fragment (AL 4a).

Fig. 3. Archéocyathes de l'écaïlle tectonique de Caunes–Minervois. (1) *Anthomorpha margarita* BORNEMANN; fragment d'intervallum, MNHN M84265 (AL 15a.2). (2) *Anthomorpha immanis* DEBRENNE; section longitudinale avec excroissances exocyathoides à la base, MNHN M84266 (AL CMO). (3) *Protropharetra stipata* DEBRENNE; section transversale d'un calice jeune, MNHN M84261 (AL 2.2). (4) *Dictyocyathus* cf. *verticillus* (BORNEMANN); section transversale d'un calice étiré, MNHN M84263 (AL 15a.1). (5) Carinacyathidae; section longitudinale montrant les canaux non-communiquants en S, MNHN M84268 (AL 15c.2). (6) ?*Afiacyathus* sp.; rares synapticalae, MNHN M84267 (AL 1). (7) ?*Chouberticyathus* sp.; section transversale, le squelette est remplacé par de la sparite (AL 15b). (8) *Anthomorpha margarita* Bornemann; section transversale basale avec tabulae vésiculaires, MNHN M84264 (AL 2). (9) *Erismacoscinus* cf. *elongatus* (BORNEMANN); section oblique longitudinale, MNHN M84259 (AL 6). (10) *Inessocyathus levis* DEBRENNE; section longitudinale oblique, MNHN M84258 (AL 1a). (11) *Erismacoscinus* cf. *calathus* (BORNEMANN); fragment d'intervallum (AL 4a).



Middle Cambrian strata, and is not indicative of a distinct biostratigraphic level (Matthews and Missarzhevsky, 1975; Brasier and Singh, 1987; Landing, 1988, 1991; Missarzhevsky, 1989; Bengtson et al., 1990; Landing and Bartowski, 1996), although its species could display biostratigraphic utility. This genus is known in Europe from England and Scandinavia (Fisher, 1962). An old report of a single finding from Germany (Schwarzbach, 1934: "...slim and round small rods maybe belong to the genus *Hyolithellus*...") is ambiguous. No further findings are reported since then, and re-investigation is not possible because the material is neither figured nor described, and was lost during the Second World War.

Phylum, Class, Order and Family uncertain

Genus *Yunnanodus* WANG and JIANG (in Jiang, 1980)

Type species: *Yunnanodus dolerus* WANG and JIANG (in Jiang, 1980).

Diagnosis: Small (about 1 mm), spine-shaped sclerites with small basal plate, the latter bearing short denticles; thin wall, of unknown composition; internal cavity extending throughout the spine length of spine (after Wang and Jiang (in Jiang, 1980); Qian and Bengtson, 1989).

Yunnanodus dolerus WANG and JIANG (in Jiang, 1980).

1980 *Yunnanodus dolerus* nov. sp. (Jiang, 1980, p. 86; pl. 2, Figs. 13–16).

1980 *Yunnanodus doleres* (Luo et al., 1980, pl. 1, Fig. 11).

1984 *Yunnanodus doleres* (Xing et al., 1984, pl. 10, Fig. 6).

1984 *Yunnanodus doleres* (Qian, 1984, pl. 3, Figs. 9–10).

1984 *Yunnanodus doleres* (Luo et al., 1984, pl. 11, Fig. 7).

1989 *Yunnanodus dolerus* (Qian and Bengtson, 1989, Figs. 44–45).

Yunnanodus cf. *dolerus* WANG and JIANG (in Jiang, 1980),

Fig. 5(4–5).

Description: Tooth-like fragments consisting of a flat, more or less slightly concave base (plate), with a large internal cavity, and one predominant straight spine flanked by several minor denticles. The cavity continues into the slightly inclined main spine. The latter is about 1 mm long with a basal diameter of about 430 μm . Its cross-section is circular and very slightly flattened. The phosphatic wall is corroded, so that its detailed internal structure is not visible; rib-like features on spine and denticles seem to be related to preservational conditions. Four flanking minor denticles are preserved (three on one side, one on the opposite one). Their length decreases with distance from the main spine: the largest (and nearest) denticle is 280 μm long, and the smallest (and distal) 200 μm . The denticles show a slightly flexural aspect, and point to the same direction than the main spine. Their cross-section is not determinable.

Discussion: Despite its poor preservation, the specimen described shows all the characters necessary to assign to the conodont-related genus *Yunnanodus* WANG and JIANG, 1980 (in Jiang, 1980), presently a monospecific taxon (*Yunnanodus dolerus* WANG and JIANG, 1980 (in Jiang, 1980)), and hitherto known only from the middle Meishucunian of south China. The sclerite presented herein differs from Wang and Jiang's description by the apparent fewer number of minor denticles (this, however, could be an effect of preservation) and a larger plate. Nevertheless, specimens described and illustrated by Qian and Bengtson (1989) coincide with the French material in such a fewer number of (bent) denticles. A difference between the French specimen, the type species and Qian and Bengtson's specimens is the shape of the main spine, which is straight in the former and slightly curved in the latter ones. Furthermore, the length of the denticles is slightly bigger in the French specimen (200–280 μm), in contrast to the Chinese forms which are 100–150 μm . Comparing the type material from Wang and Jiang (in Jiang, 1980), the specimens of Qian and Bengtson (1989) and the Lastours one, their morphological differences appear to be of minor importance, quite possibly representing intraspecific morphological variability. Further

Fig. 4. (1) *Torellella mutila* MISSARZHEVSKY, 1989; strongly curved initial part with ring-like structures; see two slightly developed keels and the low angle of divergence (R 11084). (2) *Torellella mutila* MISSARZHEVSKY, 1989; a detail of the enlarged initial part of the previous tube with well-preserved ring-like structures (R 11084). (3) *Torellella mutila* MISSARZHEVSKY, 1989; growth lines on the middle and flattened part of the tube (R 11085). (4) *Torellella mutila* MISSARZHEVSKY, 1989; clearly visible regular growth lines on the flattened part of a specimen displaying a low angle of divergence (R 11086). (5) *Torellella lentiformis* (SYSOIEV, 1962); distinct increase of the tube's angle of divergence (R 11087). (6) *Torellella lentiformis* (SYSOIEV, 1962) (R 11088). (7) *Torellella lentiformis* (SYSOIEV, 1962); distinct increase of the tube's angle of divergence and well-developed growth lines (R 11089). (8) *Torellella lentiformis* (SYSOIEV, 1962); more irregular growth lines on the middle part of the tube (R 11090). (9) *Torellella* sp. indet. (R 11091). All scale bars = 500 μm , except 4.2, 4.6 and 4.8 where = 200 μm .

Fig. 4. (1) *Torellella mutila* MISSARZHEVSKY, 1989; partie initiale fortement courbée munie de structures ressemblant à des anneaux; il est remarquable la présence de deux légères quilles et l'angle faible de divergence (R 11084). (2) *Torellella mutila* MISSARZHEVSKY, 1989; détail de la partie initiale du tube antérieur montrant des structures ressemblant des anneaux bien préservées (R 11084). (3) *Torellella mutila* MISSARZHEVSKY, 1989; stries d'accroissement sur la partie médiane et aplatie du tube (R 11085). (4) *Torellella mutila* MISSARZHEVSKY, 1989; stries régulières d'accroissement nettes sur la partie aplatie de l'exemplaire qui montre un angle faible de divergence (R 11086). (5) *Torellella lentiformis* (SYSOIEV, 1962); augmentation nette de l'angle de divergence (R 11087). (6) *Torellella lentiformis* (SYSOIEV, 1962) (R 11088). (7) *Torellella lentiformis* (SYSOIEV, 1962); augmentation nette de l'angle de divergence et développement des stries d'accroissement (R 11089). (8) *Torellella lentiformis* (SYSOIEV, 1962); plan irrégulier des stries d'accroissement sur la partie moyenne du tube (R 11090). (9) *Torellella* sp. indet. (R 11091). Toutes les échelles = 500 μm , à l'exception des Figs. 4.2, 4.6 et 4.8 où sont = 200 μm .



findings and more material are necessary to clarify if attributing these morphological variations to one species is justifiable.

Yunnanodus? sp.,

Fig. 5(6–7)

Description: Two badly preserved specimens lacking denticles are questionably assigned to this genus on the basis of phosphatic conical morphologies with a strongly corroded plate and a well-preserved, straight, main spine. The latter is slightly inclined, 1.100 µm long and displays a distinct deep internal cavity. The basal diameter of the spine is subcircular and about 500 µm. The morphology of the plate is not determinable and minor denticles are not observed, both characters seemingly due to poor preservation.

The other fragmented sclerite shows a badly preserved spine, slightly curved, about 1 mm long, and contains a distinct deep internal cavity. The basal diameter of the phosphatic spine is subcircular and about 500 µm. No morphological features are visible on the surface of the spine. Minor denticles or other elements are not observed.

Discussion: These specimens differ from those assigned positively to *Y. dolerus* in the morphology of the plate, which is only partly preserved, and the primary existence of minor denticles. Because of the size and material of the sclerites, the shape and inclination of the main spine, and the existence of the characteristic internal cavity, the specimens reported here are related to the genus *Yunnanodus*. However, due to the lack of denticles (preservational aspects?), which is a diagnostic character by original definition, the specimen is reported in open nomenclature.

4. Paleocological and biostratigraphic implications

The described subunits were deposited in a spectrum of environments ranging from calm settings, seldom affected by turbulence, to those frequently washed by waves and currents. Lower energy deposits dominate the mottled limestones, whereas sediments deposited under higher conditions are floatstones and packstones. The mottled limestones are interpreted to represent deposition in a moder-

ately shallow, open-platform setting below weather wave base, but within the episodic action of storm waves. Storms were probably responsible for the generation of intraclasts, and packstone and floatstone beds. The lack of evidence for gravity-driven flow suggest that the topographic relief was minor. Neither consistent paleocurrent directions were determined nor channel-like features observed.

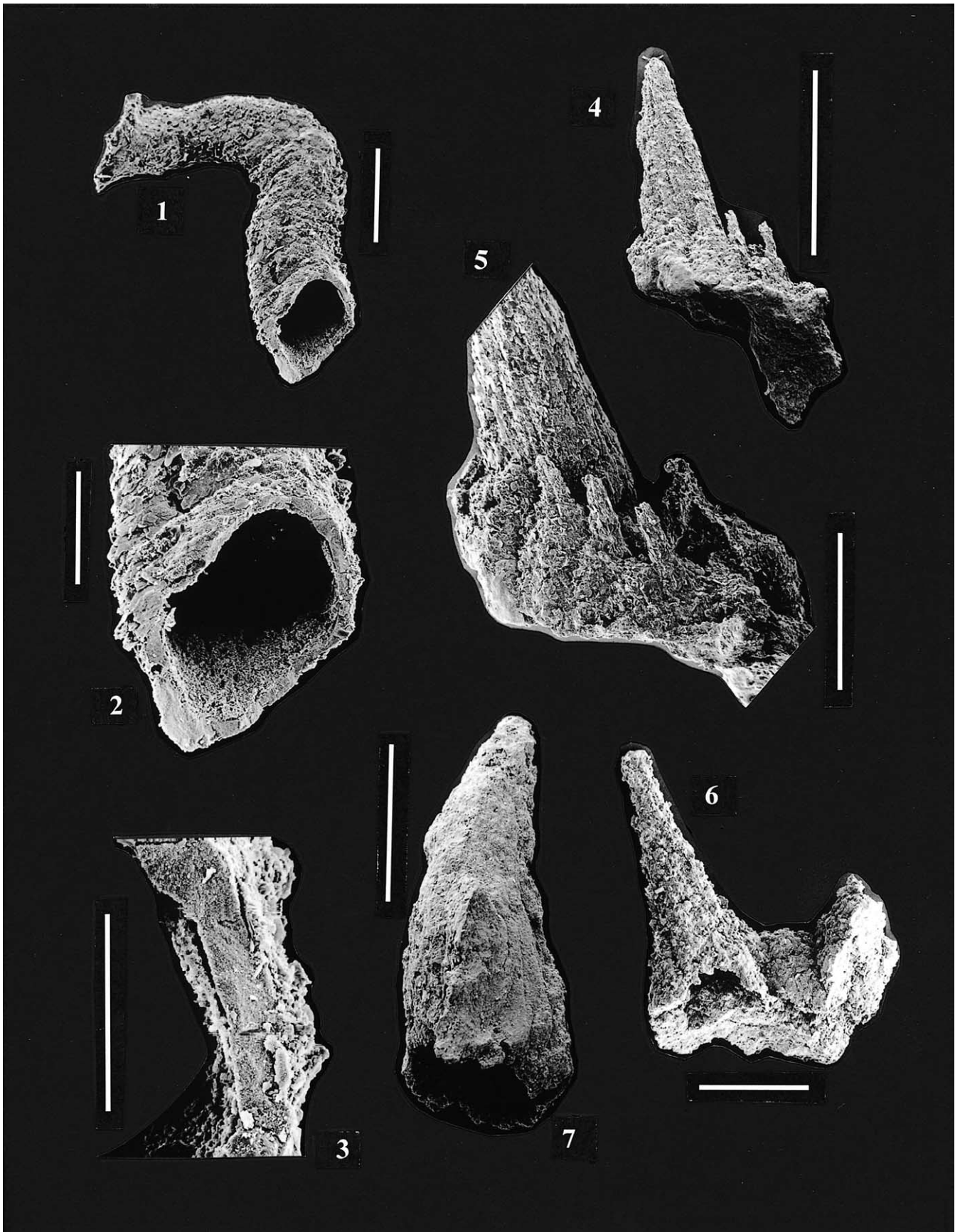
The lower member of the Lastours Formation contains the youngest archaeocyathan assemblage of the southern Montagne Noire. Fossiliferous beds in the Lower Cambrian of the Montagne Noire are scarce and bounded by thick intervening barren intervals. This is particularly true for trilobite-bearing beds, whereas archaeocyaths are found in a considerable greater number on the Pardailhan and the lower part of the Lastours Formations. In summary, the whole siliciclastic–carbonate sections of the Pardailhan Formation and the lower member of the Lastours Formation can be correlated with the Siberian Botoman stage (Fig. 2), based on the presence of the archaeocyath-index *Anthomorpha*, while trilobites appear as isolated assemblages both in the Pardailhan Formation and the upper member of the overlying Lastours Formation.

5. Conclusions

The Lastours Formation represents a small piece of a wide carbonate platform that bordered the western Gondwana margin in Early Cambrian time (Álvaro et al., 2000). The limestones of the lower member of the Lastours Formation, cropping out in the Caunes–Minervois thrust sheet (Pardailhan nappe, southern Montagne Noire), represent alternation of two marine depositional environments: relatively low energy, shallow subtidal substrates, highly bioturbated (mottled limestones); and reef flanks or inter-reef settings, containing centimetre-thick microbial patch reefs surrounded by washed archaeocyath-spiculate shelly pavements. Sedimentary structures related to wave, current and/or storm action (erosional surfaces, graded beds and packstone textures) are common, recognized as laterally correlatable layers (up to 20 cm thick), which reflect intensive washing and winnowing. The common development of

Fig. 5. (1) *Hyolithellus* sp. indet; round cross-section showing some ridges on the outer surface (scale bar = 200 µm) (R 11092). (2) *Hyolithellus* sp. indet; a detail of the previous specimen with a smooth inner surface and ridge-like ornamentation (scale bar = 100 µm) (R 11092). (3) *Hyolithellus* sp. indet; variable thickness of the three-layered wall on the same specimen; inner and outer layer altered (scale bar = 50 µm) (R 11092). (4) *Yunnanodus* cf. *dolerus* WANG and JIANG, 1980; flat base with one inclined main spine and four minor denticles (scale bar = 1 mm) (R 11093). (5) *Yunnanodus* cf. *dolerus* WANG and JIANG, 1980; a detail of the previous specimen exhibiting well-preserved four minor denticles (scale bar = 500 µm) (R 11093). (6) *Yunnanodus?* sp.; large basal cavity, corroded plate and main spine (scale bar = 500 µm) (R 11094). (7) *Yunnanodus?* sp. (scale bar = 500 µm) (R 11095).

Fig. 5. (1) *Hyolithellus* sp. indet; section transversale subcirculaire montrant quelques crêtes sur la surface extérieure (échelle = 200 µm) (R 11092). (2) *Hyolithellus* sp. indet; détail de l'exemplaire antérieur avec une surface intérieure lisse et une ornementation à partir de crêtes légères (échelle = 100 µm) (R 11092). (3) *Hyolithellus* sp. indet; épaisseur variable de la paroi composée de trois couches, l'intérieur et l'extérieur altérées (échelle = 50 µm) (R 11092). (4) *Yunnanodus* cf. *dolerus* WANG and JIANG, 1980; base plate avec une épine majeure inclinée et quatre denticules (échelle = 1 mm) (R 11093). (5) *Yunnanodus* cf. *dolerus* WANG and JIANG, 1980; détail de l'exemplaire antérieur montrant quatre denticules bien préservés (échelle = 500 µm) (R 11093). (6) *Yunnanodus?* sp.; cavité basale large, plaque corrodée et épine principale (échelle = 500 µm) (R 11094). (7) *Yunnanodus?* sp. (échelle = 500 µm) (R 11095).



microbial boundstones, abundant infaunal activity, and a diversity of shelly fauna indicate a well-oxygenated, open-marine setting. Quieter parts of the platform recorded carbonate mud substrates characterized by burrow mottling.

Due to the abundance of mud matrix there is no evidence of synsedimentary and cementation. This is corroborated by medium to high degree of bioturbation. Most of the biogenic disturbance appears as nondiagnostic, centimetre-sized mottling recognized as burrow systems. They form irregular, vertical and horizontal networks, whose fills lack any lamination and walls are sharp and sinuous. The burrow fill is composed of sucrosic dolomite reflecting cementation in a biogenically induced, diagenetic microenvironment.

An archaeocyathan assemblage (dominated by *Anthomorpha* and *Inessocyathus*) is composed of the following species: *Inessocyathus levis* DEBRENNE, 1964 (reported for the first time in the southern Montagne Noire), ?*Afiacyathus* sp., *Carinacyathidae* gen. et sp. indet, *Erismacoscinina* gen. et sp. indet, *Erismacoscinus* cf. *elongatus* (BORNEMANN, 1886), *Erismacoscinus* cf. *calathus* (BORNEMANN, 1886), *Protopharetra stipata* DEBRENNE, 1964, ?*Chouberticyathus* sp., *Dictyocyathus* cf. *verticillus* (BORNEMANN, 1891), *Anthomorpha margarita* BORNEMANN, 1886 and *Anthomorpha immanis* DEBRENNE, 1964. Phosphate-shell microfossils are dominated by hyolithelminths (genera *Hyolithellus* and *Torelrella*) and conodont-related sclerites (genus *Yunnanodus*). Other abundant but unidentified fossil debris consist of calcisponge spicules, linguliformean brachiopods, trilobite debris, hyoliths and echinoderm ossicles. The fossil assemblage is Botoman in age, dated on the basis of archaeocyaths.

From a biofacies and sedimentological point of view, the Caunes–Minervois thrust outcrops are similar to those of the Orbiel valley (whose sections were named Artigues, Caunette and Grézilhau by Debrenne, 1964), where the stratotypes of both the Pardailhan and Lastours Formations were defined (Álvaro et al., 1998a). *Retecoscinus boyeri*, relatively abundant in the underlying Pardailhan Formation (Debrenne, 1964), is absent in the lower member of the Lastours Formation. However, this lack is difficult to interpret in terms of biostratigraphy versus paleoecological conditions.

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