



***Bacinella*, a discrete type of Mesozoic calcimicrobial structure**

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Abstract: The controversy surrounding *Bacinella irregularis* RADOIČIĆ, 1959, and *Lithocodium aggregatum* ELLIOTT, 1956, has involved both sedimentologists and paleontologists. Arguments to exclude them from the Codiaceae are reviewed. The same arguments may be advanced to exclude their ascription to most other organisms. The only hypothesis resisting all elements of disproof is that of a consortium involving microbial communities. Accordingly, these structures are treated here as biosedimentary structures, namely *bacinella* structures, and not as taxa. One of the features specific to the organisms that built these structures is their strong corroding ability, as shown by the examples of fossils partly or fully cannibalized. This represents one state of corrosion beyond surficial etching and borings. Besides their capacity to corrode calcareous substrates, these microbial organisms formed nodules or oncoids and even built biostromes, which, depending on their stage of development, may have formed soft, firm or even hard substrates. However, to our knowledge, microbial communities contributing to *bacinella* structures never built up any bioherm. To complete this summary review, a building-block model that coherently takes into account most architectural variations is presented in the form of a figure sketch. The endolithic foraminifer *Troglotella incrustans*, which is commonly found associated with *bacinella* structures, is not an encruster or a borer. Lastly, contrary to certain erroneous hypotheses, no major *bacinella* episode has been ever found coeval with any significant Oceanic Anoxic Event.

Key-words:

- *Bacinella*;
- *Lithocodium*;
- *Troglotella*;
- Jurassic;
- Cretaceous

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Résumé : *Bacinella*, un type particulier de structure calcimicrobienne mésozoïque.- La controverse entourant *Bacinella irregularis* RADOIČIĆ, 1959, et *Lithocodium aggregatum* ELLIOTT, 1956, a fait s'opposer sédimentologues et paléontologues. Les arguments pour les exclure des Codiaceae sont passés en revue. Ces mêmes arguments peuvent également être avancés pour réfuter leur attribution à la plupart des autres groupes d'organismes. La seule hypothèse qui résiste alors à tous ces éléments de réfutation est celle d'une association impliquant des communautés microbiennes. En conséquence, ces structures sont ici traitées comme des structures biosédimentaires, à savoir des structures *bacinellae*, et non comme des taxons. L'une des caractéristiques propres aux organismes responsables de ces structures *bacinellae* est leur forte capacité de corrosion, comme en témoignent des exemples de fossiles partiellement ou totalement cannibalisés. Cette cannibalisation représente un état de corrosion au-delà de l'altération de surface et des perforations. Outre leur capacité à corroder les substrats calcaires, ces organismes microbiens sont capables de former des nodules ou des oncoïdes, voire même des biostromes qui, selon leur stade de développement, peuvent constituer des substrats mous, fermes, voire durs. Cependant, dans l'état actuel de nos connaissances, les communautés microbiennes contribuant à ces structures *bacinellae* n'ont jamais construit de bioherme. Pour compléter ce tour d'horizon synthétique, un modèle de construction rassemblant de manière cohérente la plupart des variantes architecturales est présenté. Quant au foraminifère endolithique *Troglotella incrustans*, fréquemment associé aux structures *bacinellae*, ce n'est ni un organisme encroûtant, ni un perforant. Enfin, contrairement à certaines hypothèses erronées, aucun épisode majeur à *bacinellae* n'a jamais été observé à la suite d'un Événement Anoxique Océanique significatif.

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**Mots-clefs :**

- *Bacinella* ;
- *Lithocodium* ;
- *Troglotella* ;
- Jurassique ;
- Crétacé

1. Introduction

The controversial nature of *Bacinella* RADOIČIĆ, 1959, and that of its "allied genus" *Lithocodium* ELLIOTT, 1956, are still the subject of endless discussions about their systematic affinities (ELLIOTT, 1963; SEGONZAC & MARIN, 1972; BANNER *et al.*, 1990; SCHMID & LEINFELDER, 1995, 1996; SCHLAGINTWEIT *et al.*, 2011a, 2011b; SCHLAGINTWEIT & BOVER-ARNAL, 2012, 2013). The present author, who was a longtime follower of André F. MAURIN's views (MAURIN *et al.*, 1985), never questioned their microbial nature (GRANIER, 1987) and did not contribute much to the debate until the 29th IAS Meeting of Sedimentology in Schlading. Except for a short report on *Bacinella* presented on the occasion of this meeting (GRANIER, 2012a), he never gathered any evidence supporting this assumption. In that connection the scope of this article is to address most significant aspects of these fossil structures. Specifically, it is a mixture of arguments based on paleophycology and carbonate sedimentology, with a discussion on erroneous hypotheses regarding some *Bacinella* temporal occurrences made by some authors, mostly geochemists (PITTET *et al.*, 2002; IMMENHAUSER *et al.*, 2005; FÖLLMI, 2008; RAMEIL *et al.*, 2010; HUCK *et al.*, 2010).

2. Material

With respect to *bacinella* structures, the present author revised material used for his PhD thesis (GRANIER, 1987). It consists of Berriasian specimens from Puig Campana (Province of Alicante, Spain) and lower Albian specimens from Serra Gelada/Sierra Helada (Province of Alicante, Spain; the spelling Serra Gelada will be used in the remainder of this paper). The middle Berriasian material comes from the unit 3, *i.e.*, "*Neotrocholina Oolites*" of the "*coupe de la brèche de Roland*" (*op. cit.*: Fig. 5) on the western flank of the Puig, whereas the Albian material comes from several sections located in the Parc Natural de la Serra Gelada that span unit 5, *i.e.*, the "Limestones with Rudists and Oysters":

1. SW section, "*coupe de Luis Menchu*", Beni-dorm (GRANIER, 1984: Figs. 7-8, Pls. 2-3; 1987: Fig. 27);
2. NE section, "*coupe du relais*" (GRANIER, 1987: Fig. 23), from the top of the marine cliff to the electrical substation, "L'Albir Radar Àllo-más" (435 m), L'Alfàs del Pi;
3. NE section, "*coupe des carabiniers*", L'Alfàs del Pi (GRANIER, 1984: Fig. 9; 1987: Fig. 25).

As for *Troglotella*, an endolithic foraminifer commonly associated with *bacinella* structures, and examples of borings, the material presented comes from various locations (Algeria, Brazil, United Arab Emirates) that are documented in Table 1.

3. Historical summary regarding the nature of *Bacinella*

ELLIOTT (1963) and later SEGONZAC and MARIN (1972) regard *Bacinella* and *Lithocodium* either as one single organism or as structures built by a single organism. For instance, as early as 1963, ELLIOTT (*op. cit.*: p. 295) states "it seems likely that *Lithocodium* and *Bacinella* may be constructed by the same organism". In contrast, other authors may have regarded *Bacinella* and *Lithocodium* as discrete organisms and may even have erected more new species. Although, according to the International Code of Botanical Nomenclature (or the International Code of Zoological Nomenclature), *Lithocodium* should have priority over *Bacinella* (*e.g.*, BANNER *et al.*, 1990; KOCH *et al.*, 2002), the popularity of *Bacinella* exceeds by far that of *Lithocodium*. Note that SCHLAGINTWEIT and BOVER-ARNAL (2013), as ELLIOTT (1963) before, use the original spelling of *Bačínella* with a caron or inverted circumflex (ˇ) placed over the (c), which means that the correct spelling of *Bačínella* should be *Batchinella*, not *Bacinella*.

SCHLAGINTWEIT and BOVER-ARNAL (2013) reviewed all the *Bacinella* representatives to date but, except for *Lithocodium aggregatum*, their list does not include any other *Lithocodium* representatives. However, it looks like *Lithocodium japonicum* ENDO, 1961, and *Lithocodium morikawai* ENDO, 1961, both from the Torinosu Limestone (Upper Jurassic of Japan), are "nearly identical" with *Lithocodium aggregatum*. They also summarize and discuss various ascriptions of similar structures to green algae, red algae, foraminifers, sponges, microbial structures (MAURIN *et al.*, 1985), and consortia of microbes or microbes with other organisms. For instance, as already pointed out by CHERCHI and SCHROEDER (2006) and by SCHLAGINTWEIT and BOVER-ARNAL (2013), some *Bacinella*-like structures may have mistakenly been considered as an incrusting foraminifer with agglutinated alveolar walls, similar to *Coscinophragma* (SCHMID & LEINFELDER, 1995, 1996). Reciprocally, as documented here, some foraminifers may have mistakenly been interpreted as representatives of *Lithocodium* (*e.g.*, *L. regularis* JOHNSON, 1968: Pl. 2, fig. 3; Pl. 1, figs. C-D herein; *op. cit.*: Pl. 4, figs. 6-7; Pl. 1, figs. A-B herein). Finally, SCHLAGINTWEIT and BOVER-ARNAL (2013) also contribute to the debate and put forward their own interpretations.



Table 1: List of material studied (thin sections).

Sample, thin section	Lithostratigraphic unit, chronostratigraphic unit	GPS coordinates	Locality, country
PC 16463 (28/03/1982)	<i>Aloisalthella</i> Limestones, Tithonian-lower Berriasian ("Calcaires à Clypéines")	ca. 38°35'21.5"N 0°12'27.4"W	Puig Campana, Finestrat, Alicante, Spain
Brèche 7 / ZC16547 (25/03/1983)	<i>Neotrocholina</i> Oolites, middle Berriasian ("Oolithes à Néotrocholines")	ca. 38°35'51.0"N 0°12'11.0"W	Puig Campana, Finestrat, Alicante, Spain
Brèche 29 / ZC16635 (25/03/1983)	<i>Coscinoconus</i> Limestones, upper Berriasian ("Calcaires à Trocholines")	ca. 38°35'54.1"N 0°12'15.7"W	Puig Campana, Finestrat, Alicante, Spain
Dj3a (19/05/1985)	Coral Biolithites, middle Albian ("Biolithites de Madréporaires")	ca. 38°31'34.6"N 0°24'35.1"W	Cabeço d'Or, Busot, Alicante, Spain
HL 232 (25/07/1984)	<i>Aloisalthella</i> Limestones, Tithonian-lower Berriasian ("Calcaires à Clypéines")	38°33'06.3"N 0°03'39.1"W	Serra Gelada, L'Alfàs del Pi, Alicante, Spain
Carabiniers 14 & 15 / HL 114, HL 115 45x60 & HL 115bis (11/06/1984)	Limestones with Rudists and Oysters, lower Albian ("Calcaires à Rudistes et à Huîtres")	38°34'03.3"N 0°03'22.5"W	Serra Gelada, L'Alfàs del Pi, Alicante, Spain
Relais 24 / HL 740 (01/05/1985)	Limestones with Rudists and Oysters, lower Albian ("Calcaires à Rudistes et à Huîtres")	38°33'20.2"N 0°03'43.6"W	Serra Gelada, L'Alfàs del Pi, Alicante, Spain
TC 029 & TO 18	Kimmeridgian		Saharan Atlas, Algeria
3020 & 3022, USNM 43016 & USNM 43019	upper Tithonian-Berriasian		Blake Escarpment, offshore E Florida, U.S.A.
US34, 8954'	Arab Formation, Kimmeridgian		Umm Shaif, offshore Abu Dhabi, U.A.E.
US 221D, 6157'1"	Kharaib Formation (member no. 3), lowermost Aptian		Umm Shaif, offshore Abu Dhabi, U.A.E.
Cafuz 6 / Cafuz 6.2-A	Riachuelo Formation, ?lower-middle Albian	ca. 10°47'41.6"S 37°16'52.8"W	Fazenda Cafuz, Sergipe Basin, Brazil

The name *Lithocodium*, created by ELLIOTT (1956, 1957) and made from the combination of the ancient Greek λίθος, *lithos* (stone), and the name of a living alga *Codium*, is misleading. Starting with ELLIOTT (1956) and until recently, many authors ascribed it to the Codiaceae. However, this assumption is not tenable (GRANIER, 2011): Codiaceae are green giant unicellular algae. Their cortex is composed of utricules and their medulla of a mesh of siphons. These siphons are not septate (SCHLAGINTWEIT *et al.*, 2011a, 2011b). Unlike to calcimicrobial structures, Codiaceae are not known as encrusters in the fossil record and modern species are either lightly or not mineralized: If they were green algae, their calcareous coating would most probably be aragonitic, not calcitic

(GRANIER, 2012c). Additionally, Codiaceae are not known to corrode any calcareous substrate. Actually, most remaining options (green algae, red algae, foraminifers or sponges) are hardly defendable hypotheses, which leaves us with the microbial interpretation and/or that of structures built by more than one organism, including some microbes.

Because one cannot refer to micropaleontology and/or to paleophycology to name such biosedimentary structures (note: similarly, coated grains, stromatolites, or reefs are not given binomial Linnean names), there is also no need to refer to taxonomy when dealing with them. Similarly, the use of "bacinellid structures" (initiated by

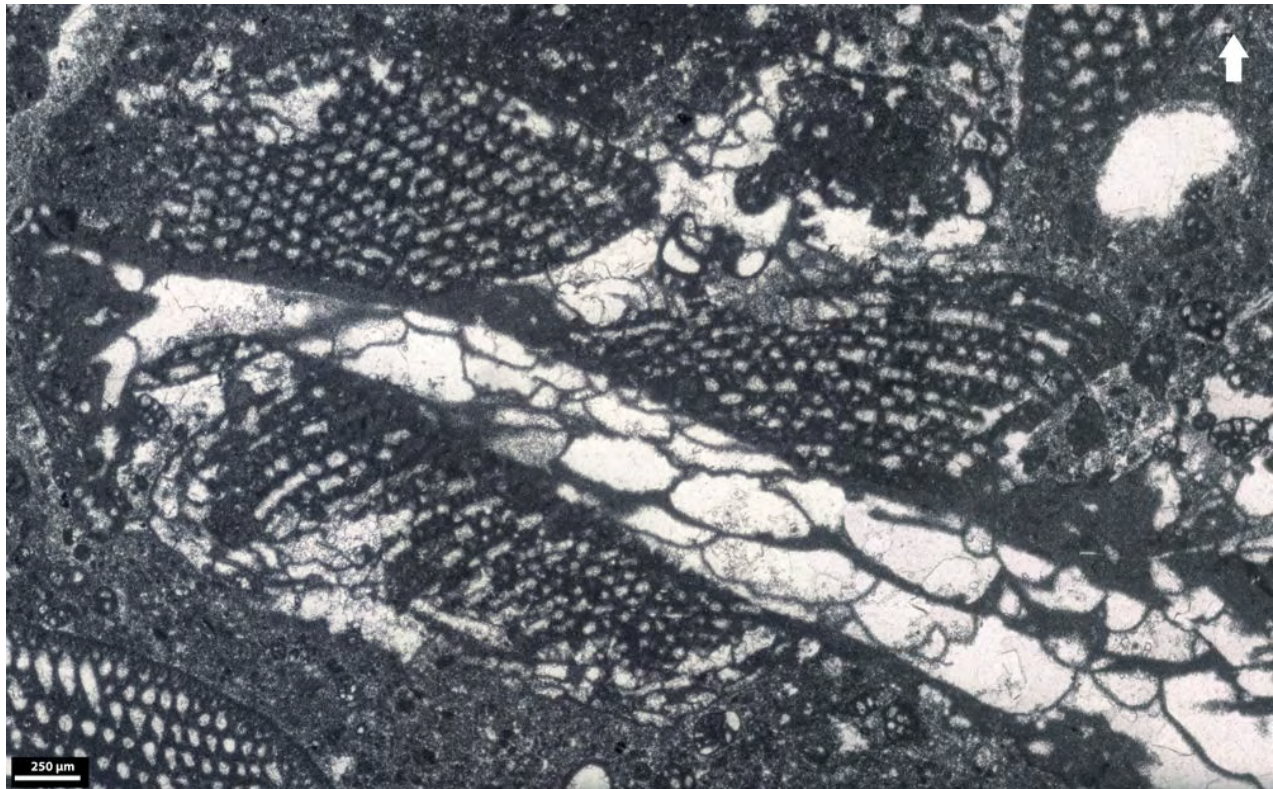


Figure 1: Orbitolinidae corroded by *bacinella* structures (excerpt of GRANIER, 1987: Pl. 50, fig. g), "Limestones with Rudists and Oysters", lower Albian, Serra Gelada, L'Alfàs del Pi, Alicante (Spain). Sample Relais 24, thin section HL 740 01/05/1985. Thick white arrow is upward-oriented. White scale bar = 250 μ m.

MAURIN *et al.*, 1985) should be abandoned because the suffix *-id* may have a taxonomic connotation (at the level of the family for animals). The use of "bacinelloid structures" is no better either because both suffixes *-id* and *-oid* are derived from the same ancient Greek word εἶδος, *eidos* (looking like). It is suggested here that both generic names *Bacinella* and *Lithocodium* be abandoned, and that these biosedimentary structures be referred to as "*bacinella* structures" (pronounced "batchinella", and with no first capital as in *Bacinella*) or *bacinellae* (plural).

4. The corroding ability of the organisms that built *bacinella* structures

The CHERCHI and SCHROEDER (2013) regard the type-material of *Lithocodium aggregatum* ELLIOTT, 1956, as "a calcimicrobial crust, infested by boring sponges (ichnotaxon *Entobia*)". Plate 2, figs. A-C, documents an oyster shell with genuine *Entobia* cavities for comparison with ELLIOTT's material. The latter display typical scalloped edges and are partly filled with calcareous chips, which are carving by-products. A dense boring network affecting another oyster shell is also illustrated in Plate 2, figs. D-E. In both cases similarities with *bacinella* structures are quite superficial. The bifurcating "tubules" of *Lithocodium* grow up from basal "vesicles" toward the external surface of the crust whereas, in genuine *Entobia* borings,

"exploratory threads" or "intercameral canals" radiate in all directions from the clionid "chamber", but not necessarily toward the external surface.

Demospongiae spicules are locally found in *bacinella* structures. Because these spicules were originally siliceous, although silica was leached and the moldic cavity later cemented by calcite, their shapes are still preserved. In many cases it could be difficult to discriminate spicule sections from sections of *bacinella* "tubules". In Plate 3, figs. C, E, fusiform shapes perpendicular to "tubules" have been proven to be spicules. In Plate 3, fig. D, some circular shapes could also be sponge spicules. Because sponge spicules 1) form the skeleton of siliceous sponges, which could be infested by the organisms that built *bacinella* structures (e.g., CHERCHI & SCHROEDER, 2006), 2) could be part of the agglutinated grains forming the test of Orbitolinidae (and sometimes called "calcite eyes", e.g., Pl. 3, figs. A, D), or 3) were commonly dispersed in the muddy matrix, no direct relationship between siliceous sponges and *bacinella* structures can be established.

SCHLAGINTWEIT and coauthors (SCHLAGINTWEIT *et al.*, 2011a, 2011b; SCHLAGINTWEIT & BOVER-ARNAL, 2012, 2013) consider that both *Bacinella* RADOIĆIĆ, 1959, and *Lithocodium* ELLIOTT, 1956, are Ulotrichalean algae that, in addition to growing in pre-existing cavities (including borings), could have "excavated complex biogenic branching galleries into biogenic hard substrates" at some stage of their development. According to BANNER *et*

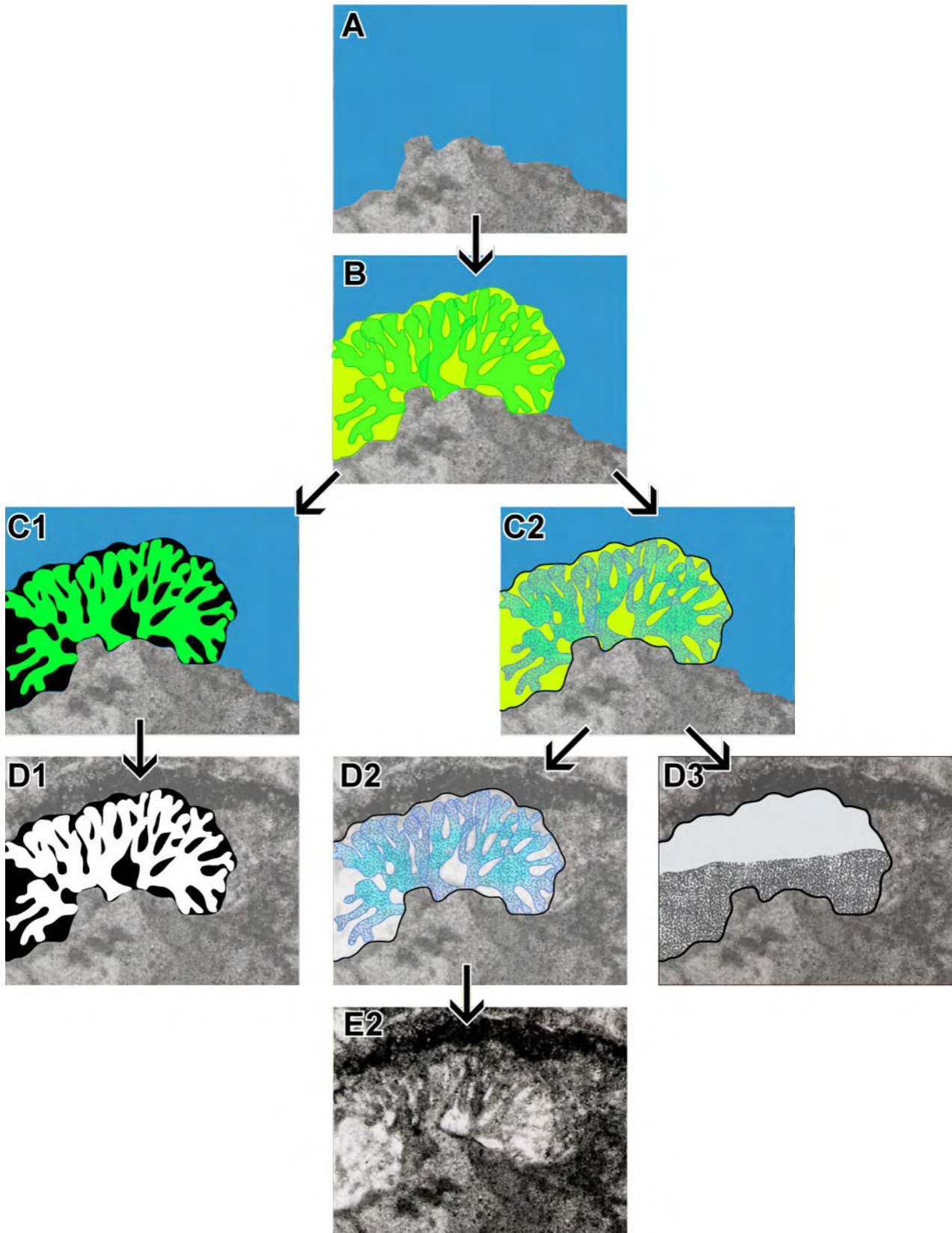


Figure 2: Conceptual model of *bacinella* growth with three proven or probable end-products. This model is based on sample Brèche 7, thin section ZC16547, "*Neotrocholina Oolites*", middle Berrasian, Puig Campana, Alicante (Spain). See description in the text.



al. (1990), "Where relatively large biogenic skeletal fragments have been previously bored, the medullary filaments of encrusting *L. aggregatum* may fill these borings so closely that the impressions may be gained, erroneously, that the encrusting alga had, itself, created the borings!"

If Ulotrichales and clionids are plausible organisms for the origin of some marginal borings in any calcareous substrate (e.g., corals, mollusk shells, and microbial crusts), both hypotheses should be rejected because they do not provide consistent explanations for:

1. the cannibalization of some large foraminifers. From the "coupe du relais" (Serra Gelada, L'Alfàs del Pi, Alicante, Spain), GRANIER (1987: Pl. 50, fig. g; Fig. 1 herein) describes a "microstructure de type *bacinella* cariant des Orbitolinidae" (i.e., a *bacinella* microstructure corrodant Orbitolinidae) in the lower Albian "Limestones with Rudists and Oysters" of the "coupe du relais". That is the first robust record of the bioeroding capacity of the organisms that built *bacinella* structures. SCHLAGINTWEIT *et al.* (2013: Fig. 2) illustrates similar patterns. In some cases, Orbitolinidae are almost fully cannibalized (Pl. 3, figs. F-G);

2. the full corrosion of some aragonitic shells (e.g., some gastropods and the aragonitic layer of some rudists) and the partial corrosion of some calcitic shells (e.g., some oysters and the calcitic layer of some rudists). The caption of GRANIER's (1987) fig. a of Plate 18 (= GRANIER, 2003: Fig. 3) Fig. 3.B herein, mentions the "niveau stromatolithique [*sic*] à structures de type *bacinella*" (i.e., microfacies of a stromatolite layer with *bacinella*-like structures), in the lower Albian "Limestones with Rudists and Oysters" of the "coupe des carabiniers" (Serra Gelada, L'Alfàs del Pi, Alicante, Spain). Fig. 3.B herein illustrates a detail of this *bacinella* biostrome (GRANIER, 1984: Pl. 5, fig. a). The caption of his fig. j of Plate 23 (GRANIER, 1987, 2003: Fig. 4), Plate 4, fig. E herein, states that the microfacies corresponds to that of "un stromatolithe [*sic*] à structure *bacinella*" (i.e., a stromatolite with a *bacinella* structure), and that it comprises "des sections de Rudistes cariés par les organismes microbiens" (i.e., rudist sections corroded by the microbial organisms). For instance, Plate 3, figs. H-J, and Plate 4, figs. F, H-I, ? C, illustrate some corroded rudist shells whereas Plate 4, fig. D, illustrates a corroded (?) gastropod shell;

3. the large and more or less dense patches of *bacinella* mesh mimicking soap foam (GRANIER, 1984: Fig. 11; 1987: Fig. 26) and forming *bacinella* boundstones (GRANIER, 1987: Pl. 18, fig. A; Fig. 3.B herein);

4. the common occurrence of geopetally arranged internal sediment, micrite to microsparticle, in many *bacinella* "bubbles"/"envelopes".

Because no other hypothesis can explain the facts reported above, the hypothesis that these structures are of microbial nature provides a robust justification for the abandonment of the binomial Linnean classification and for the use of "*bacinella* structures" when referring to them.

5. An alternative hypothesis regarding the origin of *bacinella* structures

An accreted *bacinella* nodule from the middle Berriasian "*Neotrocholina Oolites*" in the "coupe de la brèche de Roland" (Puig Campana, Finestrat, Alicante, Spain) is quite singular because next to *bacinella* "bubbles" either empty, partly filled or fully filled by internal sediment, other "envelopes" enclose bushy filamentous structures similar to small *cayeuxia* structures (GRANIER, 1987: Pl. 52, fig. e; 2003, Fig. 6; Pl. 5, fig. C herein). This nodule shows various degrees of preservation and it looks like *bacinella* "bubbles" represent specimens where filaments were either loosely mineralized or not mineralized. Fig. 2 presents a conceptual model of *bacinella* building with three proven or probable end-products.

Some soft bushy filaments (Fig. 2.B) grow on a calcareous substrate (Fig. 2.A), e.g., a *bacinella* oncoid in the case studied. Departing from that there are 3 options:

1. occurrence of microbial micrite in place of the mucilage and EPS (i.e., extracellular polymeric substances) between the bifurcating filaments (Fig. 2.C1). The decay of the organic matter of the threads (Fig. 2.C1) leaves behind empty tubular pores;

2. mineralization along the threads (Fig. 2.C2) preceding the decay of the organic matter. Strong mineralization (Fig. 2.D2) leads to the fossilization of the filament bush (Fig. 2.E2) whereas a weaker mineralization leads to the collapse of the bush coating and its geopetal accumulation as an internal micritic sediment (Fig. 2.D3);

3. lack of mineralization of the mucilage, EPS and filaments leads to the formation an empty "envelope" (not illustrated here), quite similar to a "micritic envelope" (*sensu* BATHURST, 1966).

To summarize, tubules in micrite look like the so-called "*Lithocodium*", empty or partly filled "envelopes" look like *bacinella* "bubbles", and calcified bushy filaments look like small *cayeuxia* structures, as illustrated in Plate 5, figs. A-D.

6. Soft, firm or hard *bacinella* structures

Bioturbations may have affected large *bacinella* structures. Plate 4, figs. A-B, shows two burrows. Their occurrence in a *bacinella* mesh suggests that the latter was forming a soft to firm substrate.

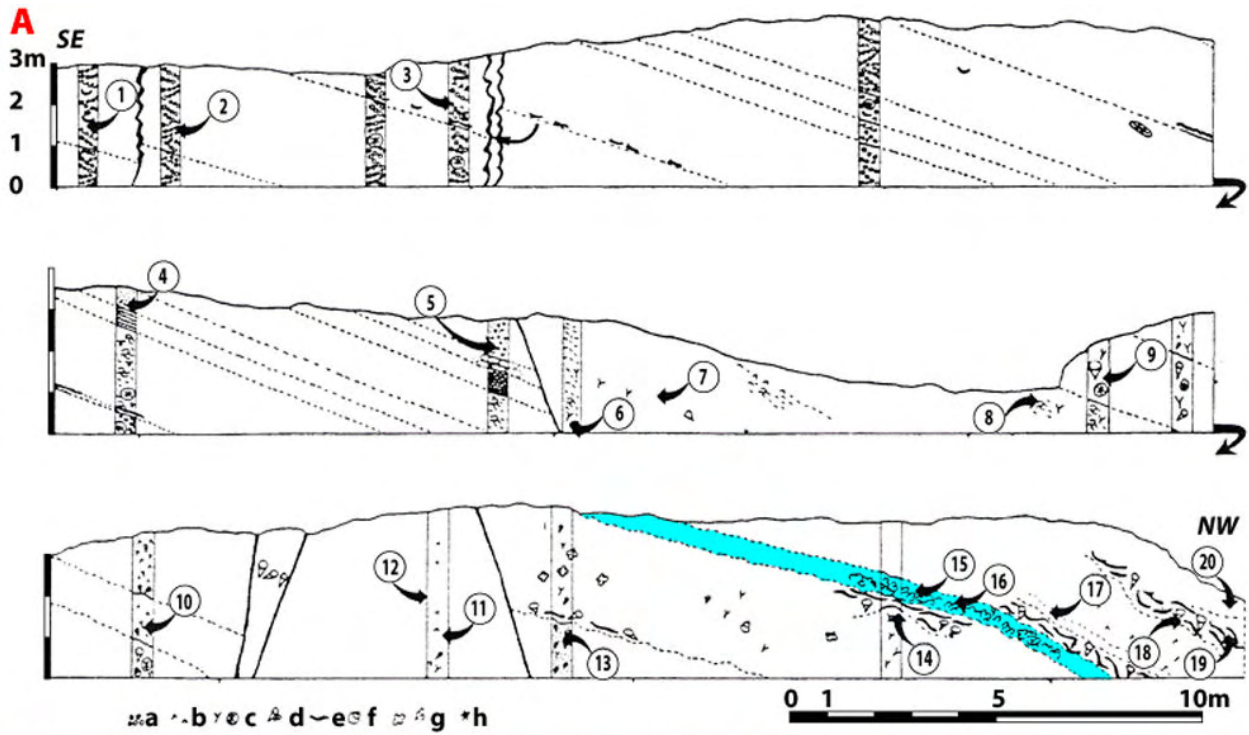


Figure 3: A) The "coupe des carabinieri" in L'Alfàs del Pi (GRANIER, 1984: Fig. 9; 1987: Fig. 25; 2003: Fig. 2) spans the lower Albian "*Cylindroporella Oolites*" and "Limestones with Rudists and Oysters". The latter comprises a *bacinella* biostrome high-lighted in a blue color in the figure. Caption: a. ooids, b. Orbitolinidae, c. corals, d. rudists, e. oysters, f. gastropods, g. *bacinella* structures, h. echinoderm remains; B) Photo of the *bacinella* biostrome with vague marbled laminations seen at the outcrop (excerpt of GRANIER, 1984: Pl. 5, fig. a).



Plate 4, fig. G, and Plate 6, fig. I, (GRANIER, 1987: Pl. 51, fig. c) show pholadid boring, *i.e.*, *Gastrochaenolites* ichnosp., in spongiostromata to *bacinella* structures. Such occurrences suggest that, at some stage, the *bacinella* structures were forming firm to hard substrates.

Plate 6, fig. B, shows a tubular and flexuous boring affecting *cayeuxia* to spongiostromata to *bacinella* structures, and that is often ascribed to *Troglotella*. Many authors (WERNER, 1986; SCHLAGINTWEIT, 1991, 2008, 2010; LEINFELDER *et al.*, 1993; SCHMID & LEINFELDER, 1995, 1996; KOŁODZIEJ, 1997; CHERCHI & SCHROEDER, 2000) consider that this endolithic foraminifer is also able to bore its own cavities. As a matter of fact, it has been observed in borings affecting echinoderm remains (Pl. 6, fig. D), corals (Pl. 6, figs. C, E), and various microbial structures, including *cayeuxia* structures (Pl. 6, figs. A-B, F); more examples are documented by SCHLAGINTWEIT (2012). It is also commonly observed inside *bacinella* structures (Pl. 6, figs. G-H). In most cases, the foraminifer wall is never attached to the cavity wall, a feature also reported from borings genuinely made by other foraminifers (*e.g.*, CHERCHI & SCHROEDER, 1991: Figs. 4-6; VÉNEC-PEYRÉ, 1987: Figs. 8-9; 1993: Pl. 1, figs. 1-8; Pl. 3, figs. 2-7). This feature suggests that, contrary to its specific epithet, *Troglotella incrustans* should not be considered as an encrusting foraminifer.

According to LEINFELDER *et al.* (1993), their "*Bullopore aff. laevis*", *i.e.*, *Troglotella incrustans* WERNLI & FOOKES, 1992, bores from a shell outer surface inwards whereas, according to CHERCHI and SCHROEDER (2000), their "*Troglotella n. sp.*" bores from a cavity inside the shell outwards. Because *Troglotella* has an imperforate test, as is the case for all agglutinating foraminifers, the first option is not acceptable. Therefore, the reconstruction of *Troglotella* boring activity by LEINFELDER *et al.* (1993: Fig. 7) is not valid because pseudopods are concentrated at the buccal plug of a single distal foramen (Pl. 6, fig. A), and are not distributed all over the test outer surface, as is the case for the hyaline tests of perforate foraminifers.

CHERCHI and SCHROEDER (2000) also noted that "La morfologia della cavità tubiforme entro la quale viveva *Troglotella* si adatta perfettamente alla morfologia esterna del guscio" (*i.e.*, The morphology of the tubular cavity within which *Troglotella* lived adapts perfectly to the external morphology of the test). However, in the present author's opinion, the opposite is true: The external morphology of the *Troglotella* test is 'more or less' perfectly adapted to the morphology of the tubular boring within which it lived. The arrangement of the chambers is uniserial in tubular cavities but becomes irregular in other cavities. CHERCHI and SCHROEDER (2000) believe that this "stadio irregolare" (*i.e.*, irregular growth stage) could have represented a final growth stage. However,

when considering *bacinella* structures only, it looks like the "stadio irregolare" is the most common stage and the uniserial arrangement the exception. This fact has been documented many times (LEINFELDER *et al.*, 1993: Pl. 42, figs. 2-7; SCHMID & LEINFELDER, 1995: Figs. 1-5; SCHMID & LEINFELDER, 1996: Figs. 3.A-B, 4.A-B, 6.A-B; Pl. 1, figs. 1-4; Pl. 2, figs. 1-5; CHERCHI & SCHROEDER, 2000: Pl. 1, fig. 8; BUCUR *et al.*, 2010: Pl. 25, figs. 4, 6-7; Pl. 62, fig. 10; SCHLAGINTWEIT *et al.*, 2011a, 2011b: Fig. 9.b, 9.d-f; BUCUR & SĂSĂRAN, 2011: Pl. 1, fig. 4; Pl. 2, fig. 5; Pl. 4, fig. 12; Pl. 5, figs. 4-6; SCHLAGINTWEIT, 2012: Figs. 1.a-b, 3.a-e, 4.a-f, 5.a-j, 6.a-d, 7.a-b, 8.a-d, 9.a-b, 12.a-b; PLEȘ *et al.*, 2013: Fig. 11.a).

The observations set out above show that *Troglotella* never was a boring foraminifer. Rather, it merely was an endolithic foraminifer. Its shizonte or its gamonte penetrated in preexisting cavities, including borings (Pl. 6, figs. A-F, I) or vugs left after the organic matter decay in *bacinella* crusts.

7. *Bacinella* structures and the question of *bacinella* biostromes versus *bacinella* bioherms

Records of *bacinella* structures were mostly coined as oncoids, *i.e.*, centimeter-sized aggregated and coated grains (DAHANAYAKE *et al.*, 1976) but never as metric to decametric geobodies. However, they may well form biostromes and, as early as 1984 (unpublished), the present author described some peculiar strata in SE Spain as consisting of "grey to whitish micritic limestones forming massive and thick beds (...), characterized by the presence of giant oysters (...) and bio-sedimentary structures of *bacinella* type, with diffuse contours or, on the contrary, forming the bulk of the rock, therefore true [*sic*] stromatolites" [*i.e.*, "des calcaires micritiques gris à blanchâtres, en 'bancs compacts' (...), caractérisés par la présence d'huîtres géantes (...) et de structures bio-sédimentaires de type *bacinella*, diffuses ou, au contraire, formant l'essentiel de la roche, soit alors de véritables stromatolithes" (GRANIER, 1987)]. Obviously, the current definition of "stromatolites" (see discussion in RIDING, 2011a, 2011b) does not fit well with the material studied and the term "microbialites" looks definitely more appropriate today to describe these large *bacinella* geobodies (GRANIER, 2003).

Per definition, the lower Albian "Limestones with Rudists and Oysters" (GRANIER, 1987), which consist of rudist and oyster floatstones with wackestone to *bacinella* boundstone matrices, yield numerous bivalve shells. As reported above smaller shells are commonly partly or fully corroded by the organisms that built *bacinella* structures (Pl. 4, figs. C-D, F, H-I).

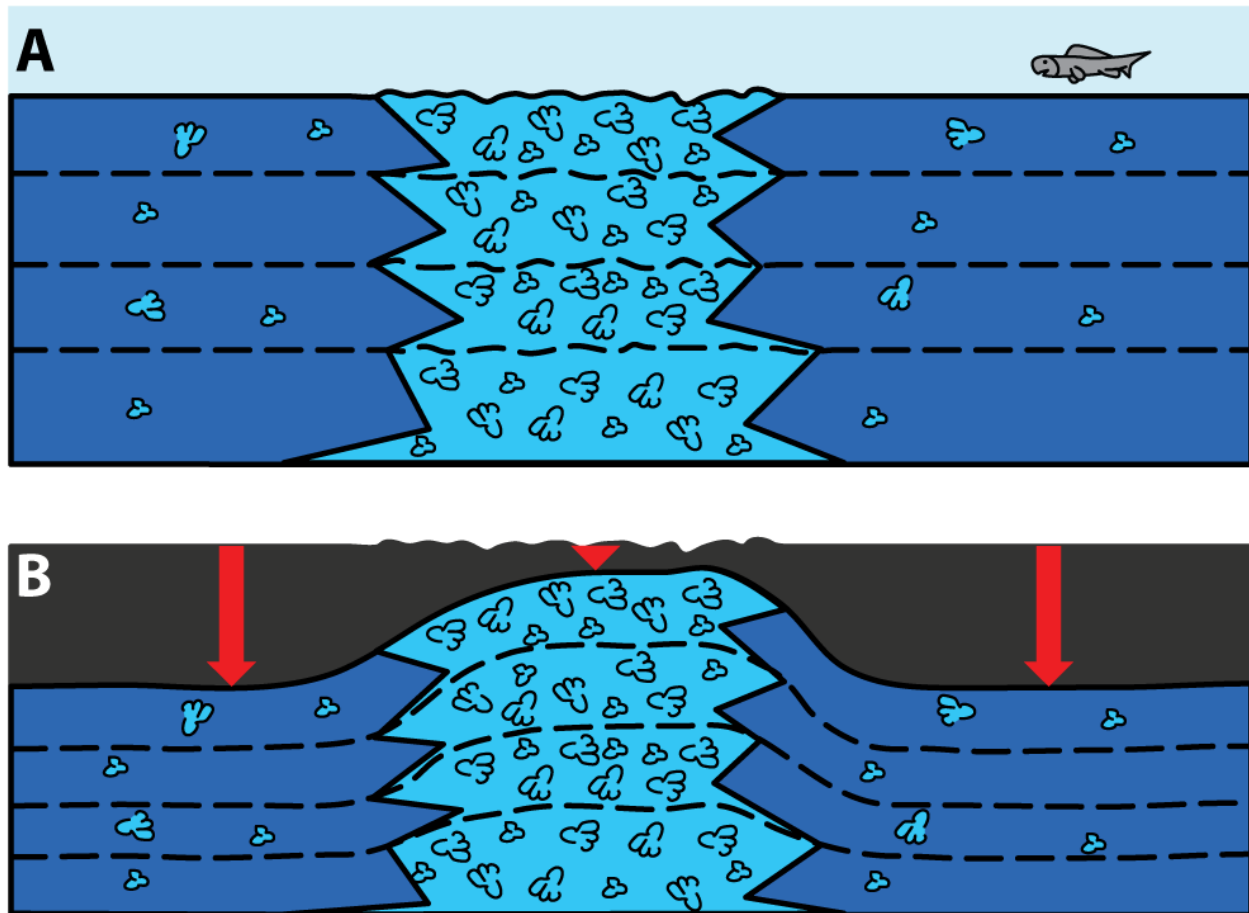


Figure 4: A) Pile of *bacinella* biostromes and scattered *bacinella* nodules in light blue color before dewatering and mechanical, then chemical compaction; B) same as above after compaction. This sketch illustrates differential compaction (red arrows). The dotted lines represent time lines.

To our knowledge, the Spanish discovery represents the first genuine record ever illustrated of a "*Bacinella* biostrome" (GRANIER, 1987: Pl. 18, fig. a). In retrospect this minor observation is more important in light of later observations.

Subsequently *bacinella* biostromes have also been reported from outcrops in Oman (PITTET *et al.*, 2002, p. 561). If *Bacinella* may well have formed biostromes, they never formed "buildups", contrary to the opinion of KOCH *et al.* (2002), IMMENHAUSER *et al.* (2005) and RAMEIL *et al.* (2010). Actually, when KOCH *et al.* (2002) consider "a vertical pile of *Lithocodium* encrustation sequences and associated rudist-lenses separated from each other by bioclastic sands" as a "*Lithocodium* (syn. *Bacinella irregularis*)-reef-mound" or as a "patch-reef", they make the mistake of describing a pile of superimposed biostromes (hence with almost no relief above the surrounding sea floor) as a buildup, which would have formed a topographic structure. A modern analog to *bacinella* biostromes could be patchy mussel banks on muddy shores. However, KOCH *et al.* (2002) were right when they demonstrated the importance of early diagenesis and differential compaction. It is suggested here that bioturbation and a lesser density of *bacinella* in the mud-

dy inter-patch areas could have played a role too, with a higher dewatering (Fig. 4) between the patches.

Differential compaction as a factor in the creation of pseudo-buildups (actually piles of biostromes, not bioherms) is neglected by IMMENHAUSER *et al.* (2005), whereas modern differential erosion is neglected by both IMMENHAUSER *et al.* (2005) and RAMEIL *et al.* (2010) when describing surface exposures.

On the basis of a supposed contemporaneity of the erroneously called "*Bacinella* blooms" with the Oceanic Anoxic Event OAE1a, some authors (PITTET *et al.*, 2002; IMMENHAUSER *et al.*, 2005; FÖLLMI, 2008; RAMEIL *et al.*, 2010; HUCK *et al.*, 2010) concluded that the two events were related. However, the contemporaneity hypothesis is contradicted by rigorous biostratigraphic (e.g., ammonites) and sequence stratigraphic data (for detailed discussion, see GRANIER, 2012b, 2014; GRANIER & BUSNARDO, 2013).

8. Conclusions

To summarize:

- Neither *Lithocodium aggregatum* ELLIOTT, 1956, nor *Bacinella irregularis* RADOIČIĆ, 1959, should be treated anymore as species but ra-



ther as biosedimentary structures, namely *bacinella* structures (pronounced "batchinella", and with no first capital as in *Bacinella*). Except for some misidentifications (e.g., *Lithocodium regularis* JOHNSON, 1968, that is a genuine agglutinating foraminifer), such structures mostly refer to microbial consortia, which can also involve other organisms (e.g., *Thaumatoporella parvovesiculifera* (RAINERI), *Koskinobullina socialis* CHERCHI & SCHROEDER, and *Troglotella incrustans* WERNLI & FOOKES).

- The growth model presented herein (Fig. 2) reaches three potential end products: 1) cavities commonly looking like foam bubbles, and either empty or partly filled with geopetal micrite to microsparite (i.e., the so-called *Bacinella irregularis* pattern), 2) outward-branching cavities with rather thick micritic walls (i.e., the so-called *Lithocodium aggregatum* pattern), and 3) small bushes of calcified branching filaments.

- At some stage in their development, *bacinella* structures can be soft to firm and bioturbated or firm to hard and bored. It is shown that *Troglotella incrustans*, which is commonly hosted in *bacinella* cavities or in pre-existing borings, is not a boring foraminifer or an encrusting foraminifer.

- The microbial organisms that built *bacinella* structures had a corroding ability; as documented above, they could etch any calcareous substrate and even fully cannibalize fossils such as Orbitolinidae, small gastropods and rudists.

- *Bacinella* structures may have formed biostromes, but never bioherms. Finally, the microbial organisms that built them did not "bloom" and no Middle-Eastern occurrence of *bacinella*-rich facies (nodules or biostromes) was ever found to be coeval with any significant Oceanic Anoxic Event.

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Plates



Plate 1: *Lithocodium regularis* JOHNSON, 1968 (upper Tithonian-Berriasian, Blake Escarpment, offshore E Florida, U.S.A.), probably a ? *Everticyclammina* sp. : A-B) excerpts of the original publication (excerpt of JOHNSON, 1968: Pl. 4, figs. 6-7), thin section Sheridan's 12S (not found); C) excerpt of the original publication (excerpt of JOHNSON, 1968: Pl. 2, fig. 3), thin section 3022, USNM 43019; D) unpublished, thin section 3020, USNM 43016; E) new microphotograph of Pl. 2, fig. 3, thin section 3022, USNM 43019. Yellow arrows point to miliolid foraminifers that were incorporated in the larger agglutinated foraminiferal test. These specimens bearing U.S. National Museum labels are stored at the Smithsonian Institution in Washington D.C. (U.S.A.). White scale bar (A-C) = 500 μm ; black scale bar (D-E) = 250 μm .

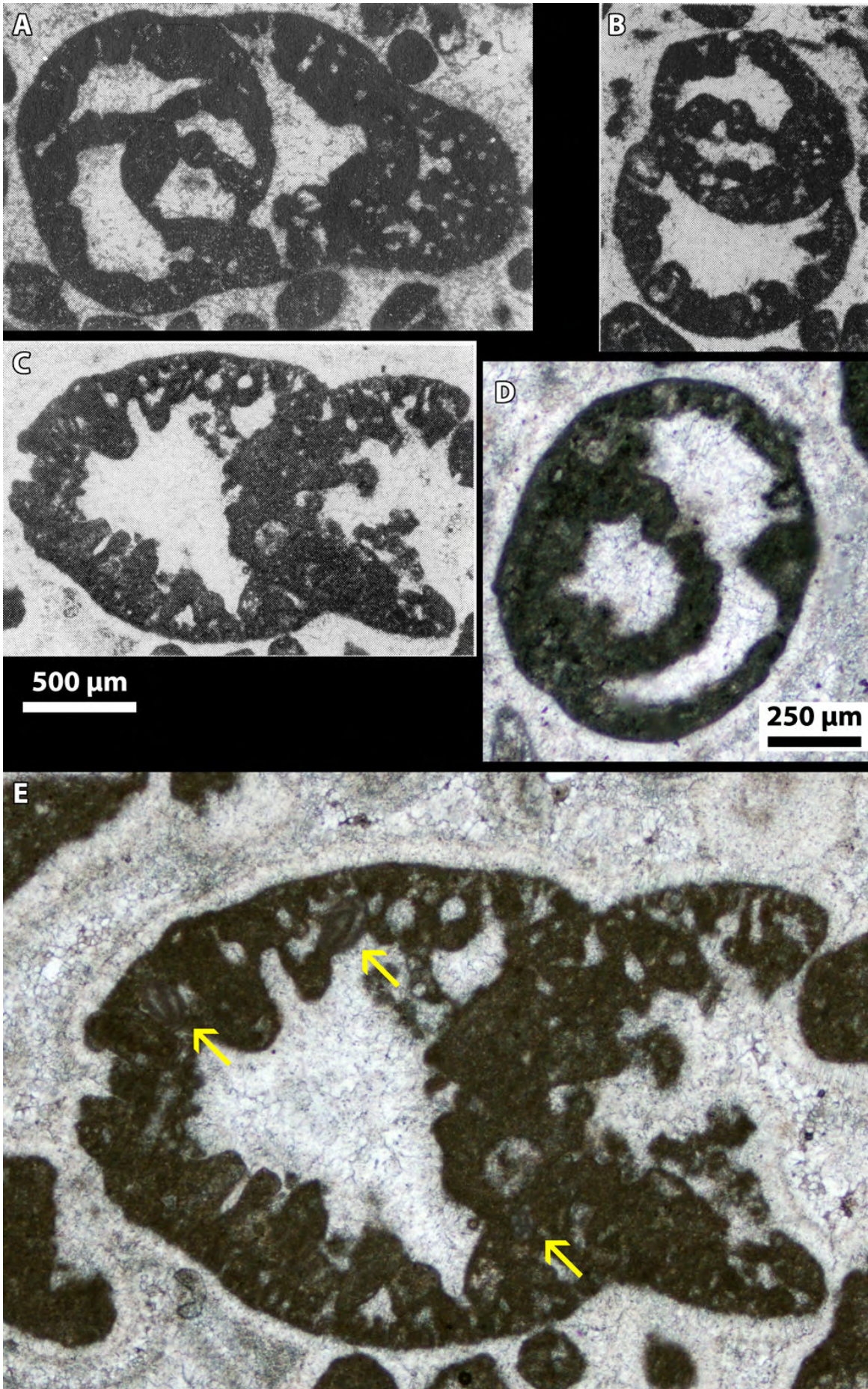




Plate 2: Examples of clionid borings, *i.e.*, *Entobia* ichnosp., in oyster shells: A-C Ph.: pholadid boring, *i.e.*, *Gastrochaenolites* ichnosp., and numerous clionid borings. Riachuelo Formation, ?lower-middle Albian, Fazenda Cafuz, Sergipe Basin (Brazil). Sample Cafuz 6, thin section Cafuz 6.2-A; D-E "exploratory threads" drilled by clionids. "Coral Biolitites", middle Albian, Cabeço d'Or/Cabazon de Oro, Busot, Alicante (Spain). Sample / thin section Dj3a 19/05/1985. White scale bars (A-C) = 500 µm; black scale bar (D-E) = 1 mm.

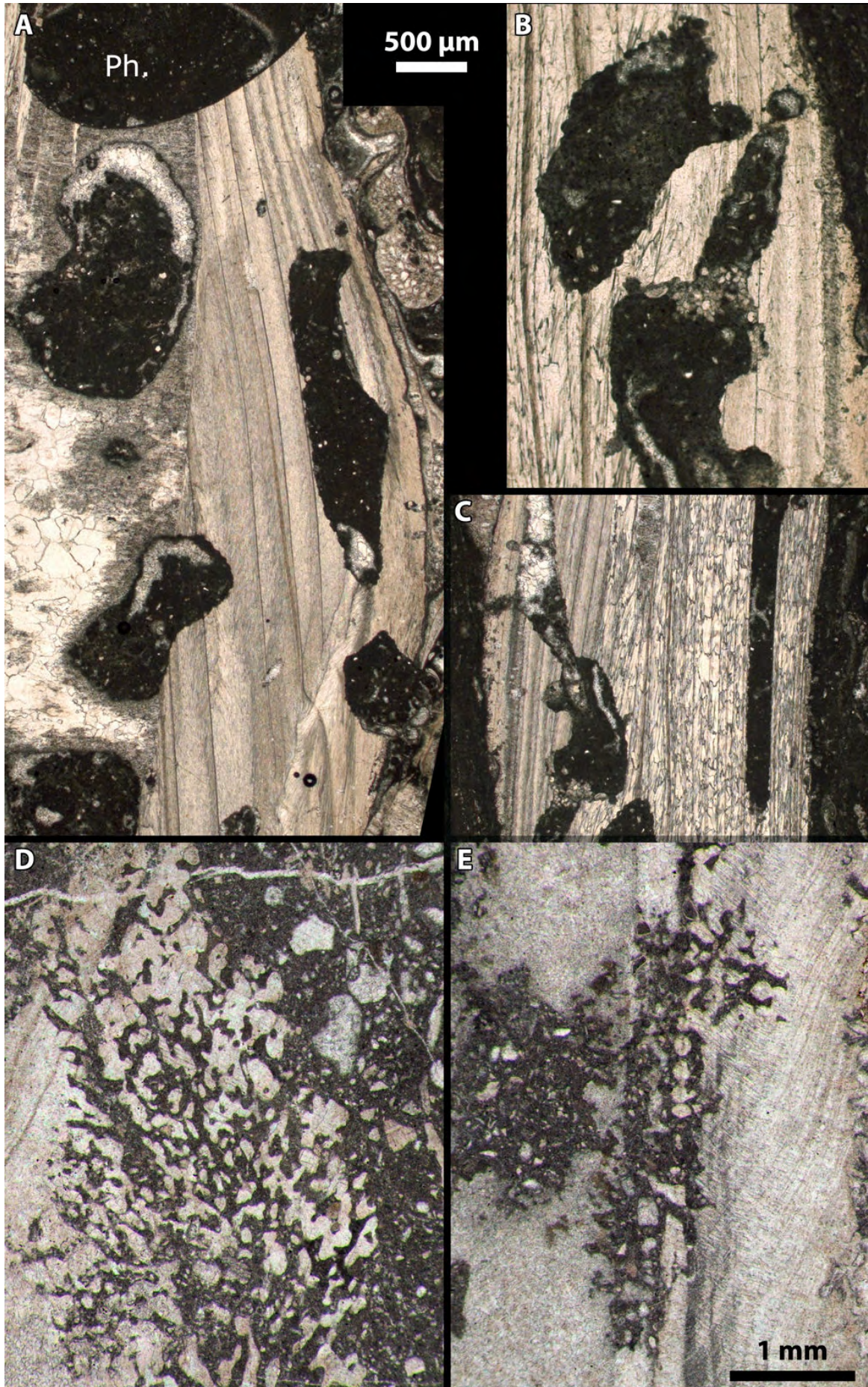




Plate 3: "Limestones with Rudists and Oysters", lower Albian, Serra Gelada, Alicante (Spain). Yellow arrowheads point to proven (*e.g.*, Pl. 3, figs. C, E) or probable sponge spicules (*e.g.*, Pl. 3, figs. A, D). A) patchy distribution of *bacinella* structures inside and outside corroded Orbitolinidae; B) crusts displaying the *Lithocodium*-like pattern; C) sponge spicules (yellow arrows) within a *Lithocodium*-like crust. The white arrow points to a small corroded calcitic bioclast embedded in the *bacinella* structure; D) detail of Plate 3, fig. A. Detail of *bacinella* structures inside and outside corroded Orbitolinidae; E) detail of Plate 3, fig. B. Sponge spicule (yellow arrows) within a *Lithocodium*-like crust; F-G) cannibalized Orbitolinidae; H) detail of Plate 3, fig. I; I) *bacinella* structures corroding bivalvia shells. Geopetal internal sediment is a micrite with slightly coarser crystals than those of the surrounding matrix; J) detail of Plate 3, fig. I. A-G) sample Relais 24, thin section HL 740 01/05/1985; H-J) sample Carabiniers 14, thin section HL 114 11/06/1984. The thick white arrow is upward-oriented. Black scale bars = 1 mm; white scale bars = 500 μ m.

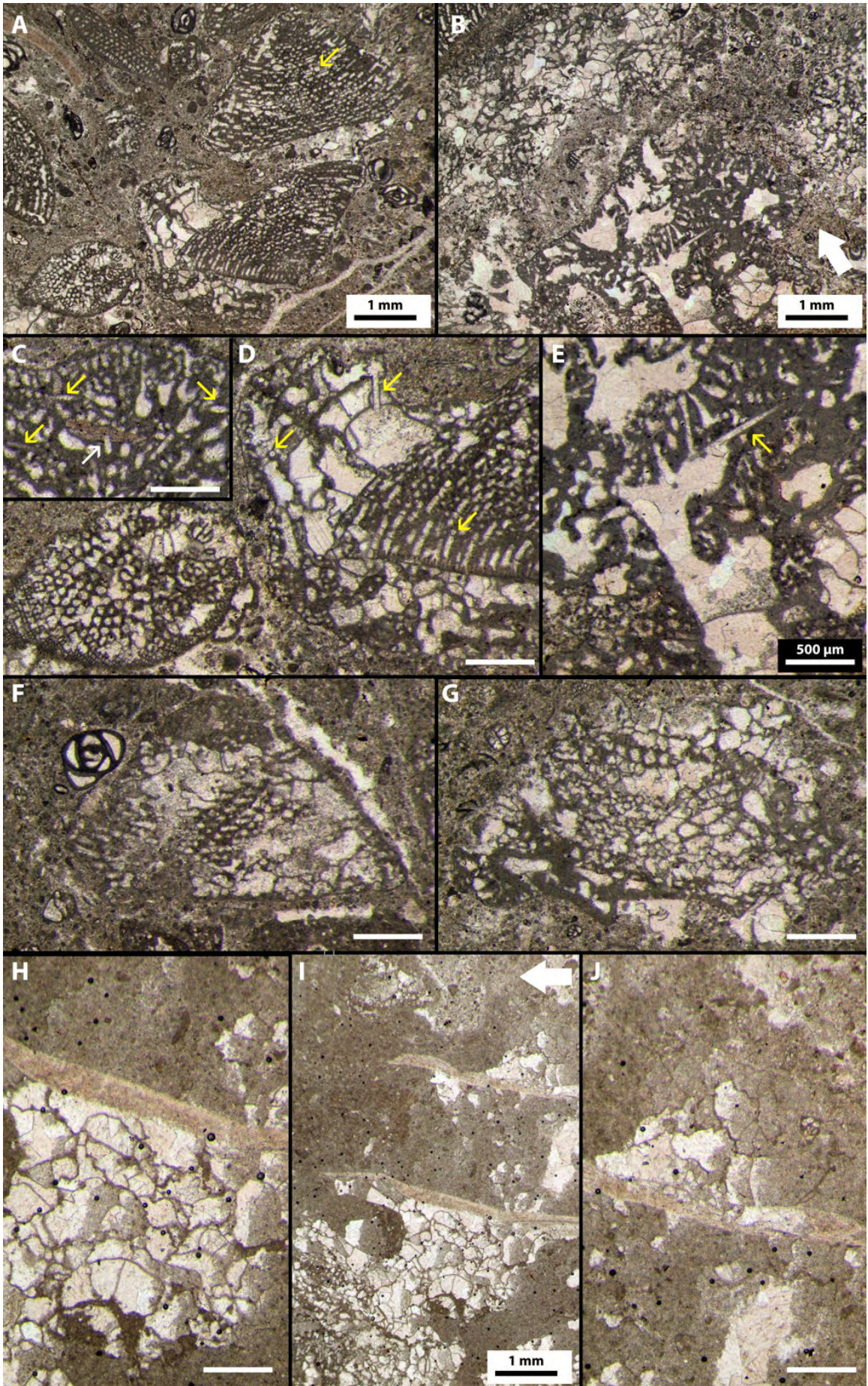




Plate 4: A-F, H-I) Photo and photomicrographs of *bacinella* boundstones from the "Limestones with Rudists and Oysters", lower Albian, Serra Gelada, L'Alfàs del Pi, Alicante (Spain): A) detail of Plate 4, fig. E. Burrow (excerpt of GRANIER, 1984: Pl. 5, fig. d); B) detail of Plate 4, fig. E. Burrow partly filled with coprolites (excerpt of GRANIER, 1984: Pl. 5, fig. c); C) detail of Plate 4, fig. E. Micritic infill of the cavity of a corroded bioclast (? rudist) embedded in the *bacinella* structure (excerpt of GRANIER, 1984: Pl. 6, fig. a); D) detail of Plate 3, fig. A. Micritic infill of the cavity of a corroded (?) gastropod shell embedded in the *bacinella* structure (excerpt of GRANIER, 1984: Pl. 6, fig. b; 2003: Fig. 8); E) photo of the thin section HL115 45x60 (excerpt of GRANIER, 1987: Pl. 23, fig. j; 2003: Fig. 4); F) corroded rudist shell embedded in the *bacinella* structure (excerpt of GRANIER, 1984: Pl. 6, fig. d; 2003: Fig. 7); H) detail of Plate 4, fig. F; I) detail of Plate 4, fig. F. Yellow arrows point to the ghost structure of a rudist shell cannibalized by the organisms that built *bacinella* structures. G) Photomicrograph of a pholadid (orange arrows) boring, *i.e.*, *Gastrochaenolites* ichnosp. (blue arrows) in a spongiostromata to *bacinella* structure from the "Aloisalthella Limestones", Tithonian-lower Berriasian, Serra Gelada, L'Alfàs del Pi, Alicante (Spain). A-E) sample Carabiniers 15, thin section HL115 45x60 11/06/1984; F, H-I) sample Carabiniers 15, thin section HL 115bis 11/06/1984; G) thin section HL 232 25/07/1984. Thick arrows are upward-oriented. Red scale bar (E) = 1 mm; white scale bar (A-D, F-G) = 500 μ m; black scale bar (H-I) = 250 μ m.

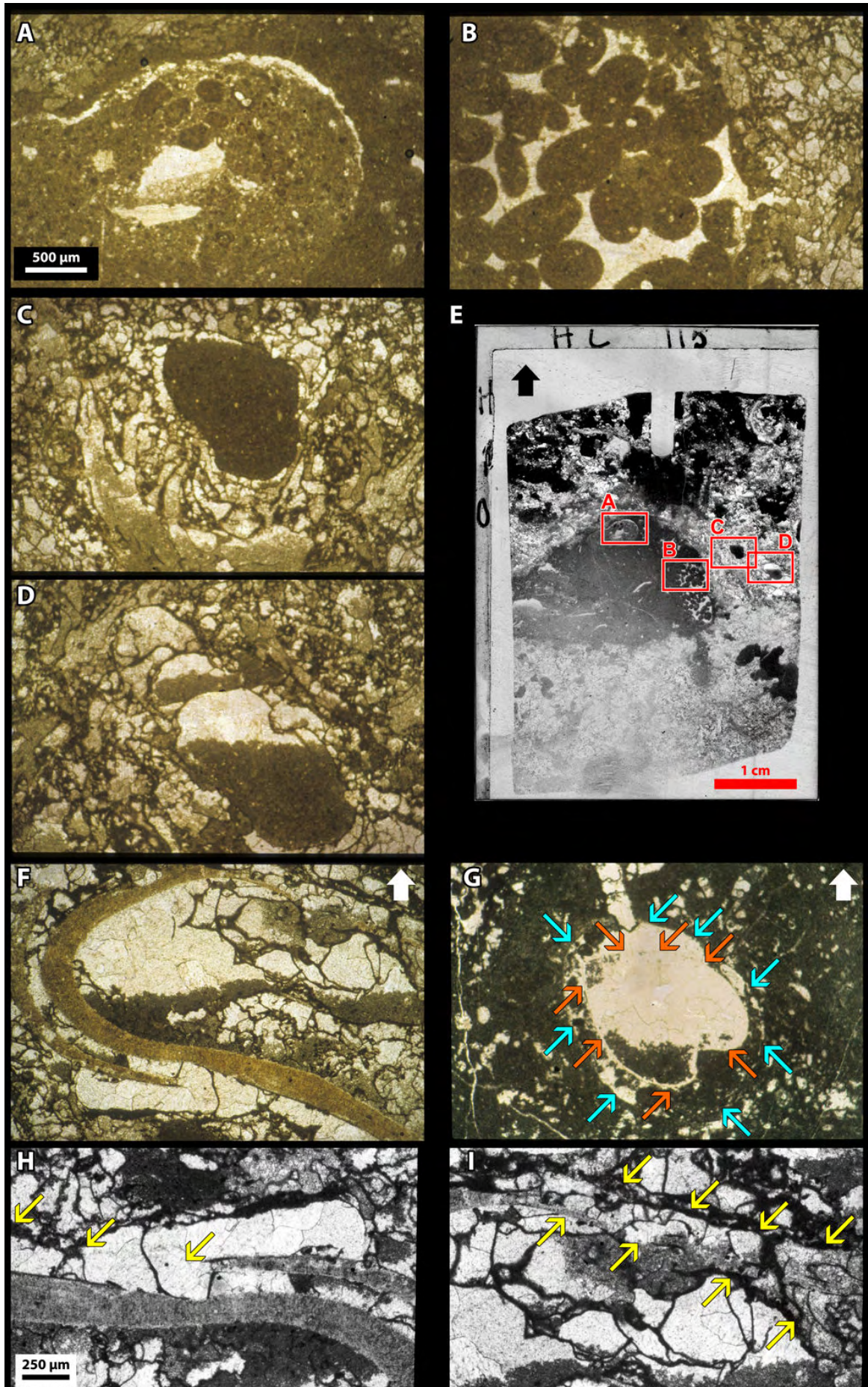




Plate 5: "*Neotrocholina Oolites*", middle Berriasian, Puig Campana, Alicante (Spain): A) nodule with *bacinella* and small *cayeuxia* structures; B) detail of Plate 5, fig. A; C) detail of Plate 5, fig. A (detail of Pl. 52, fig. e, in GRANIER, 1987; 2003: Fig. 6); D) detail of Plate 5, fig. A. A-D) sample Brèche 7, thin section ZC16547 25/03/1983. Black scale bar (A) and white scale bar (B-D) = 250 μ m.

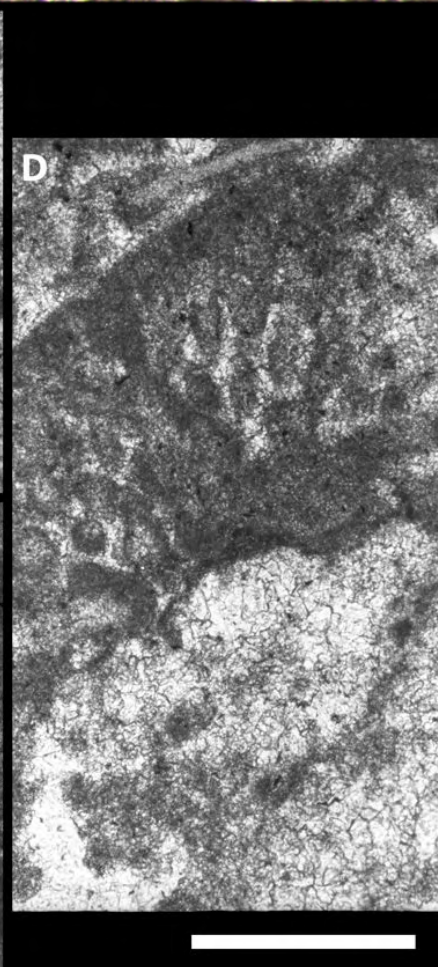
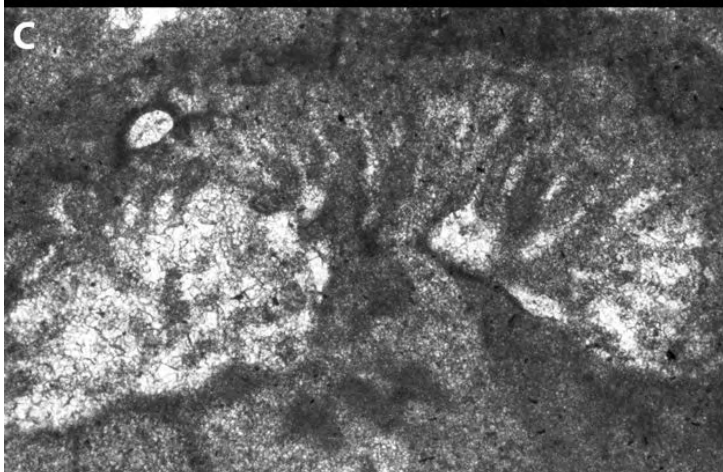
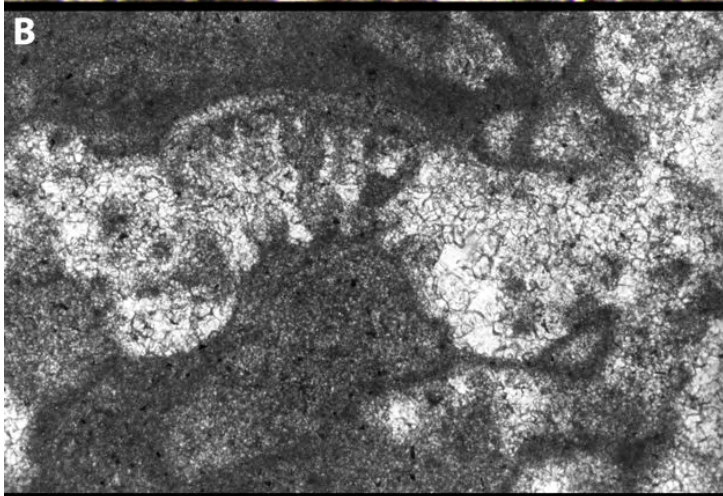
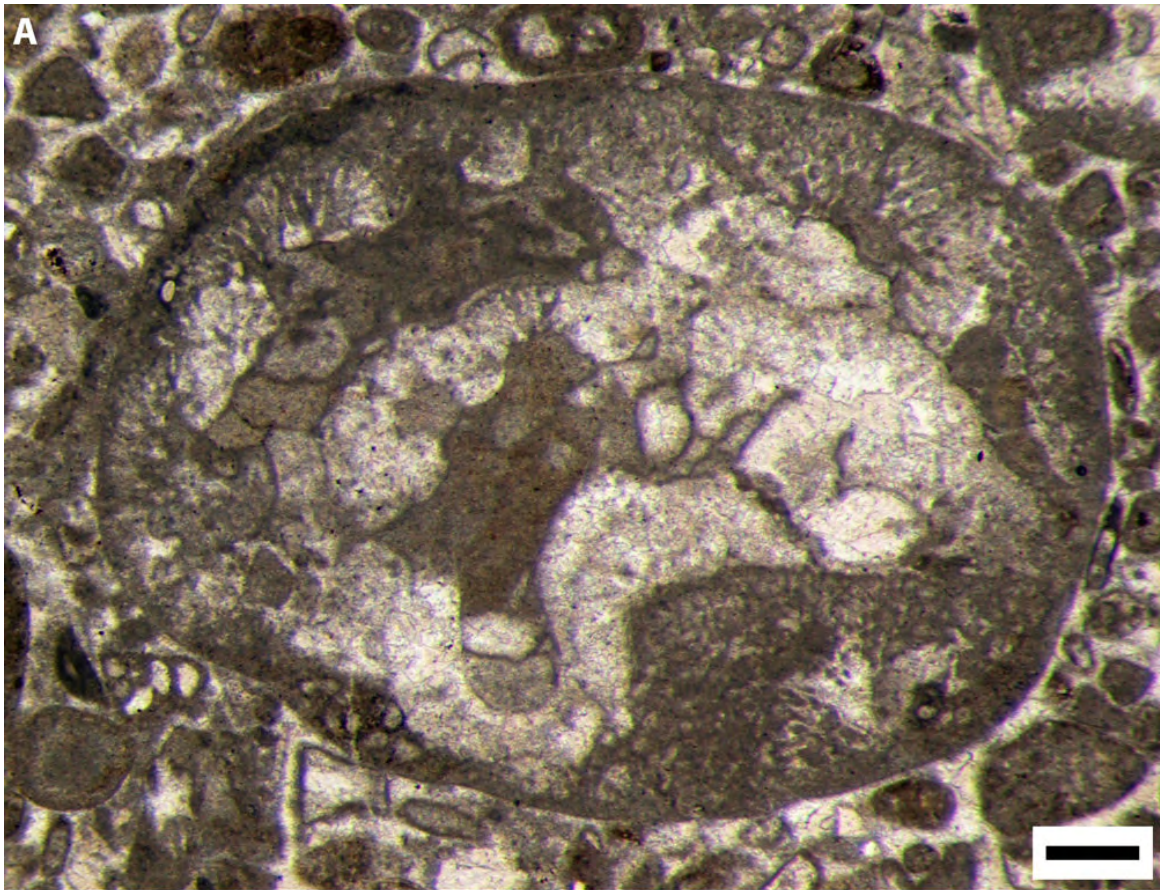




Plate 6: A-H) *Troglotella incrustans* WERNLI & FOOKES, 1992: A) detail of Pl. 6, fig. B; B) "*Coscinoconus* Limestones", upper Berriasian, Puig Campana, Finestrat, Alicante (Spain); C) borings in an eroded piece of coral from the Arab Formation, Kimmeridgian, offshore Abu Dhabi (U.A.E.); D) tubular boring in an echinoderm remain from the Kimmeridgian of the Saharan Atlas (Algeria);; E) detail of Plate 6, fig. C; F) tubular boring in a *cayeuxia* structure from the Kimmeridgian of the Saharan Atlas (Algeria); G) large cavity and H) tubular boring in a *bacinella* mesh from Kharai (3) Formation, lowermost Aptian, offshore Abu Dhabi (U.A.E.); I) Photomicrograph of a pholadid boring, *i.e.*, *Gastrochaenolites* ichnosp., in a spongiostromata to *bacinella* structure from the "*Aloisalthella* Limestones", Tithonian-lower Berriasian, Puig Campana, Finestrat, Alicante (Spain). A-B) sample ZC16635/thin section Brèche 29 25/03/1983; C, E) Umm Shaif 34, 8954'; D) TC 029; F) TO 18; G-H) Umm Shaif 221D, 6157'1"; I) sample/thin section PC 16463 28/03/1982. Red scale bar (A) = 100 μm ; white scale bar (B-C, G-I) = 500 μm and black scale bar (D-F) = 250 μm .

