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‘*Entobia* balls’ in the Medobory Biohermal Complex (Middle Miocene, Badenian; western Ukraine)

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ABSTRACT:

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The peculiarly shaped ‘*Entobia* balls’, from the Middle Miocene (Badenian) Medobory Biohermal Complex, western Ukraine, are a maze of moulds of clionid sponge borings belonging to the ichnogenus *Entobia* Bronn. The ichnospecies recognized (*Entobia geometrica*, *E. paradoxa*, *E. cateniformis*, *E. laquea*) are ascribed to the activity of two extant zoospecies, *Cliona vastifica* Hancock and *C. celata* Grant. Their habitat was provided by thick-walled shells of the bivalve *Chama gryphoides garmella* De Gregorio, the shells of which were drilled through completely. Some small patches of borings are compatible with those of the extant zoospecies *Cliona viridis* (O. Schmidt).

Key words: Clionid sponges; *Entobia*; Ichnotaxonomy; Eco-taphonomy; Diagenesis; Medobory Biohermal Complex; Miocene (Badenian); western Ukraine.

INTRODUCTION

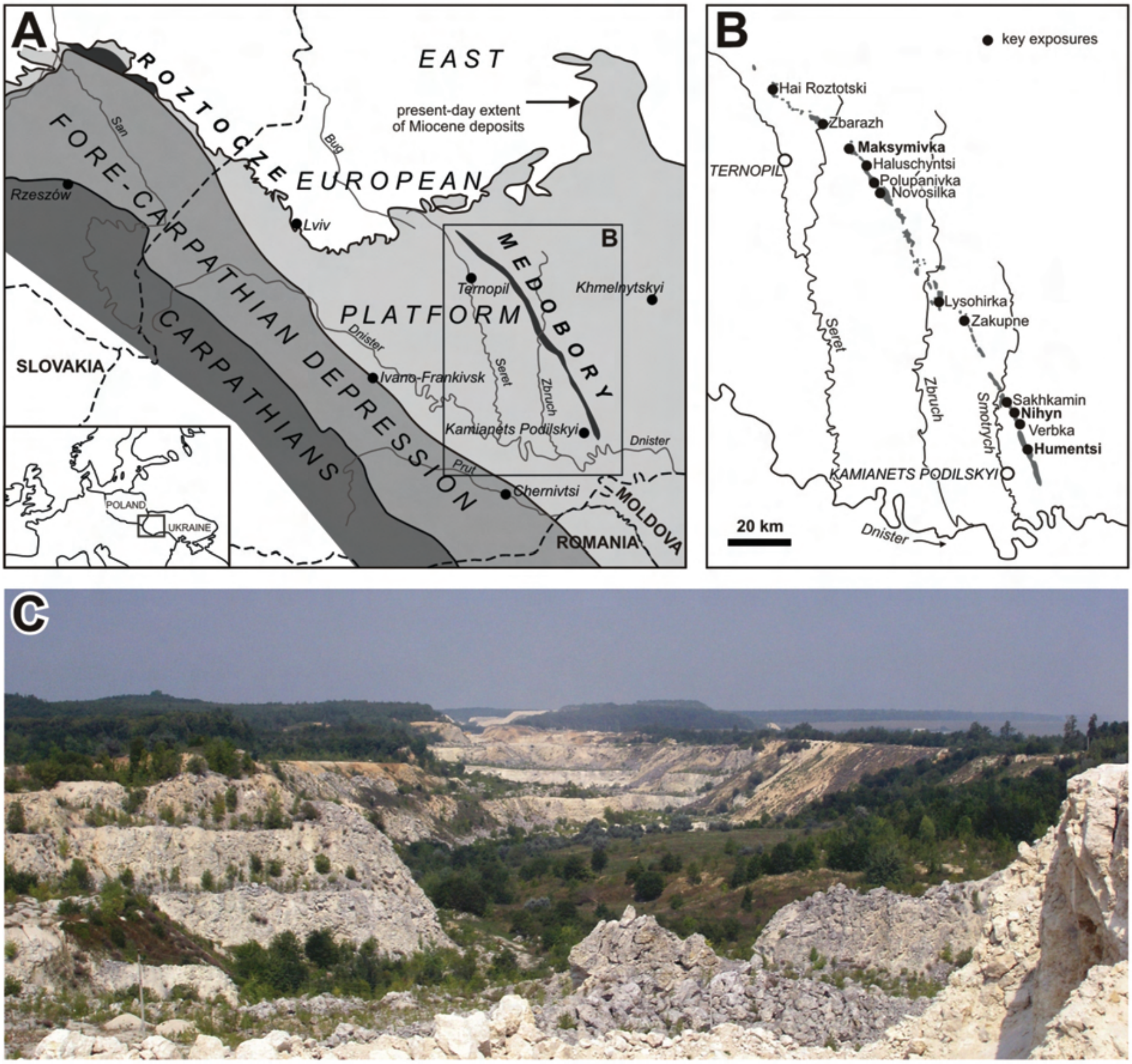
An outstanding feature of the Middle Miocene (Badenian) Medobory Biohermal Complex of western Ukraine is the abundant occurrence throughout of peculiarly-shaped, more or less spherical structures, referred to herein as the ‘*Entobia* balls’, because of their resemblance to the *sea balls* of the present-day surf zone and beaches. These relatively small oddities, averaging 4–5 cm in diameter, are composed of densely packed moulds of borings belonging to the ichnogenus *Entobia* Bronn, 1837, produced by sponges of the genus *Cliona* and/or its close relatives (family Clionidae Gray, 1867). The nature of the substrate in which the sponges were boring has long been treated as a mystery.

The aim of the present report is to demonstrate that the substrate was provided by the aragonitic shells of thick-shelled bivalves belonging to the genus *Chama* that were living in, or amidst, the algal colonies and their structures. The shells have been totally, or almost totally, dissolved by diagenesis leaving the early lithified calcitic moulds of the sponge borings intact. The manner in which the aragonite was removed is still unclear. Although aragonitic molluscan shells are generally absent from the biohermal complex (see Janakevich 1969, 1977; Radwański *et al*. 2006), aragonitic hard parts remain locally well preserved, such as large *Tarbellastraea* coral colonies at Maksymivka, or *Chama* shells at Humentsi, the source of the reference specimen.

The *Entobia* structures, having been in reality the early lithified moulds of borings, are simply termed *the borings* for brevity in the present report.

THE GEOLOGICAL AND STRATIGRAPHICAL SETTING

One of the striking lithological bodies in the Middle Miocene (Badenian) of the Fore-Carpathian Basin of western Ukraine is the Medobory Range, which ex-



Text-fig. 1. General location of the study area. **A** – Geological sketch of the north-eastern part of the Fore-Carpathian Basin in Poland and western Ukraine (see insert), to show the extent of the Medobory Range. **B** – The extent of the Medobory Range, to show its key exposures, including those of the quarries at Maksymivka, Nihyn and Humentsi. A, B adapted from Jasionowski *et al*. (2006, fig. 1A, B). **C** – General view of the Nihyn Quarry exposing the Medobory Biohermal Complex; in the foreground the upper part of the sequence which yields the '*Entobia* balls' studied

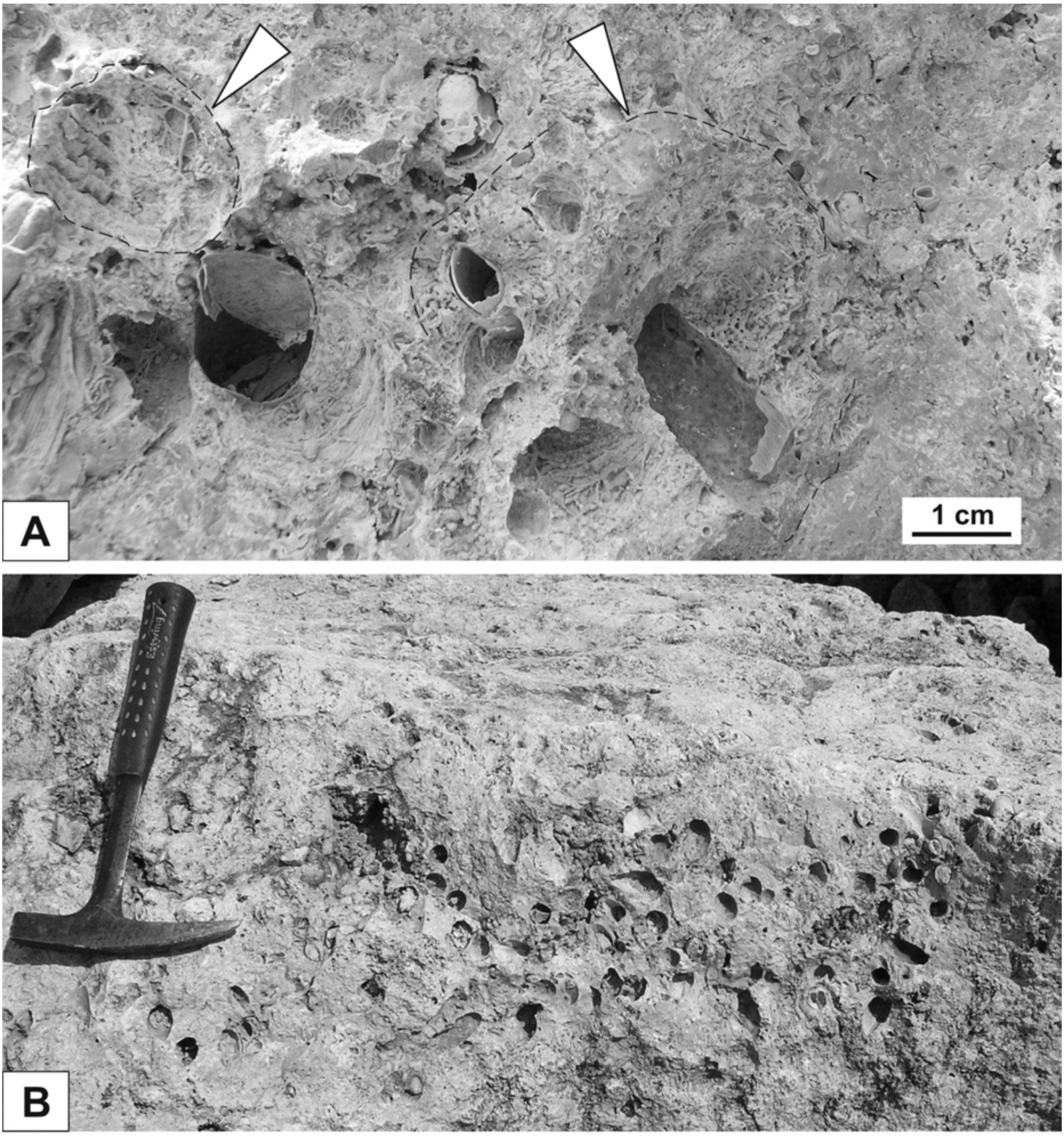
tends in the form of a narrow, hilly zone from north-western Podolia as far as the Republic of Moldova in the south-east (see Text-fig. 1A, B). It is an up to about 60 m thick buildup that represents a complex of carbonate bioherms composed of blue-green-algal mats carpeting, or crusts interwoven with, red-algal (lithothamnian) colonies of various shapes and sizes. This buildup is known as the Medobory Biohermal Complex. Its precise Badenian age remains unresolved (see Harzhauser *et al*. 2003, fig. 2; Radwański *et al*. 2006, p. 99). It is well exposed in a series of large quarries (such as Hai Roztotski, Zbarazh, Maksymivka, Nihyn, Humentsi; see Text-fig. 1B) in which its structure and biotic content may be studied in detail.

The Medobory Biohermal Complex has often been referred to as a reef, understood as a coral- or coral-bearing one (see, e.g. Dembińska-Różkowska 1932; Pisera 1996; Jasionowski *et al.* 2005, 2006). However, although isolated coral colonies, mostly *Tarbellastraea* and *Porites*, do occur in some parts of the bioherms, their general frequency is very low.

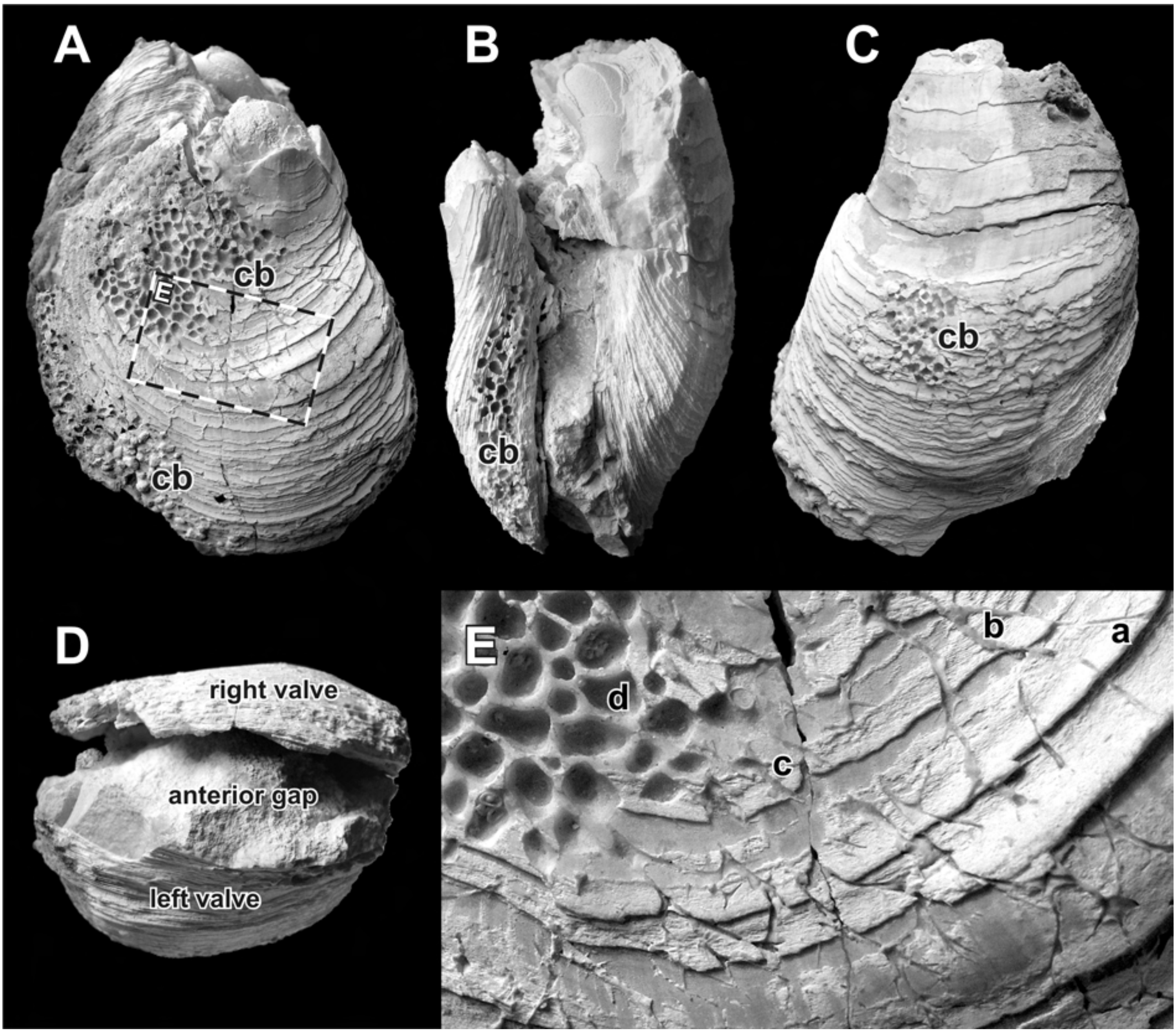
The fabric of the biohermal structures was sufficiently soft during their growth to enable the burrowing into them of alpheid shrimps (Radwański *et al.* 2006). Their tiered burrows penetrate deeply through the mats or amongst the crusts which formed simultaneously. The burrows often remained open, to act as sediment traps or animal refuges, e.g. for various crabs sheltering themselves after moulting. The whole buildup, intertidal or extremely shallow subtidal in origin, has supposedly been lithified as a result of beachrock cementation, since in some places it is densely riddled (see Text-fig. 2B) by rock-boring bivalves (mostly *Lithophaga lithophaga*, or less common *Jouannetia semicaudata* and *Gastrochaena* sp.).

THE '*Entobia* BALLS'

The '*Entobia* balls' are contained either within, or adhered to, the walls of hollow cavities resulting from the diagenetic dissolution of the bivalve shells. They all are preserved in massive and compact calcareous rocks of the Medobory Biohermal Complex (see Text-fig. 2A), from which isolated specimens cannot be extracted. The structures described here were studied and photographed in the field in the walls of the Nihyn and Maksymivka quarries and in blocks removed by quarrying (see Text-figs 5–7).



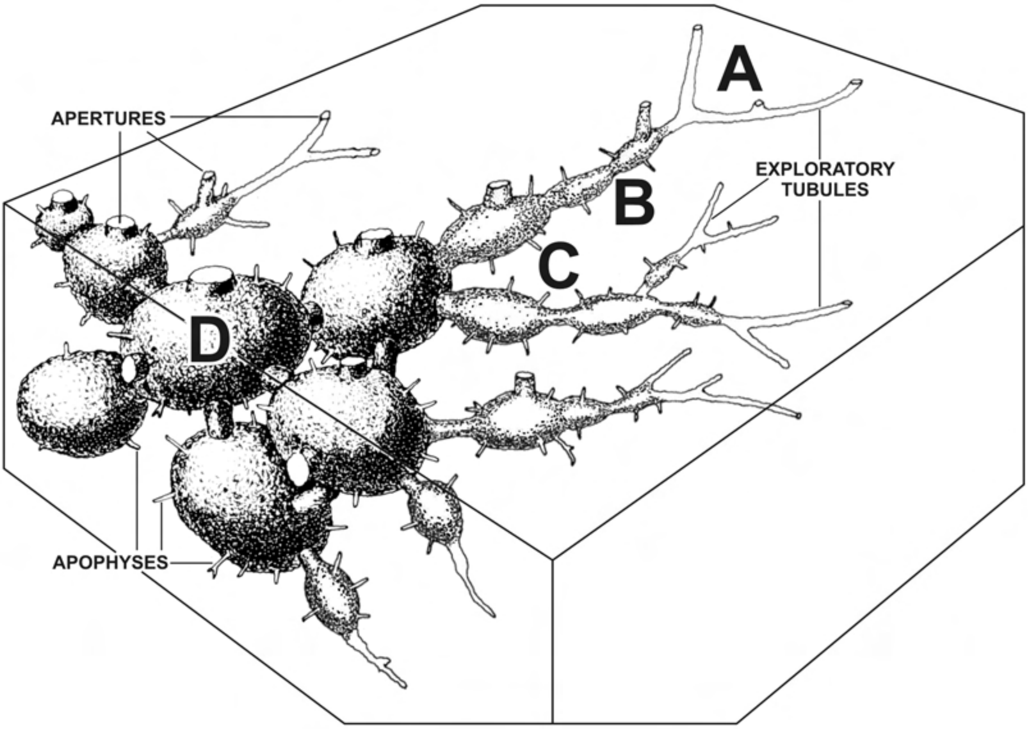
Text-fig. 2. **A** – Close-up of a quarry block, from the upper part of the Nihyn sequence, to show the '*Entobia* balls' (arrowed) in the algal matrix of the bioherm. **B** – Another quarry block, densely riddled by borings of the bivalve *Lithophaga lithophaga* (empty, exposed in oblique sections)



Text-fig. 3. The bivalve *Chama gryphoides garmella* De Gregorio, 1884 (*sensu* Friedberg 1934), probable a morphotype of *Chama* (*Psilopus*) *gryphoides gryphoides* Linnaeus, 1758 (*sensu* Schultz 2003) from Humentsi; × 0.75. **A** – Right valve view, **B** – Lateral view, **C** – Anterior view, **D** – Left valve view; Indicated are clionid borings (**cb**), patchily distributed in separate colonies; **E** – Close-up (× 5) of the borings (rectangled in Fig. A) of *Cliona viridis* (O. Schmidt, 1862), to show the growth phases (a, b, c, d = growth phasesA–D; cf. Text-fig. 4)

The *Entobia* borings are almost exclusively confined to the '*Entobia* balls', from which they occasionally extend into the surrounding matrix. The matrix is commonly densely bored by the bivalves *Lithophaga lithophaga* (Text-fig. 2B) and *Gastrochaena* sp. (see Radwański *et al*. 2006). The pear-shaped crypts (infilled borings) of the smaller-sized *Gastrochaena* occur rarely in some balls, especially those from Maksymivka (see Text-fig. 7A, B), while the larger-sized crypts of *Lithophaga lithophaga* appear sporadically in a few balls from Nihyn (Text-fig. 5/6) and in the reference specimen of *Chama* from Humentsi (see Text-fig. 3). Several balls show the polychaete borings (see Text-fig. 7A) *Maeandropolydora barocca* Bromley and D'Alessandro (Bromley and D'Alessandro (1987; see also 1983).

The type of preservation of the balls as hollow cavities filled completely by moulds of borings or with adherent moulds of borings resembles that known, for example, from Late Jurassic (Kimmeridgian) scleractinian corals (see Radwański and Roniewicz, 2005), Early Cretaceous (Albian) limestone clasts (see Marcinowski and Radwański 2009), Oligocene-Miocene bioclasts of Grand Cayman, British West Indies (Pleydell and Jones 1988), or in the Plio-Pleistocene bioclasts (?Calabrian) of southern Italy (Bromley and D'Alessandro 1987).



Text-fig. 4. Three-dimensional portion of a clionid boring, to show the growth phases: phase **A** – exploratory tubules; phases **B**, **C** – underdeveloped chambers; phase **D** – adult chambers; Partly redrawn, and modified from Bromley and D’Alessandro (1984, fig. 2)

THE BORED BIVALVE

The bored bivalve under discussion, exemplified by the reference specimen from Humentsi (Text-fig. 3), possesses a very thick shell with a multilamellar structure. The component lamellae tend to split off and scale off marginally as a result of both secretion processes during the growth of the animal and diagenetic and/or weathering processes. The bivalve is referred to *Chama gryphoides* Linnaeus, 1758, an extant species reported fossil from numerous European localities in Europe, with its first occurrence in the Early Miocene (see Friedberg 1934, Schultz 2003). Sacco (1899) distinguished several intraspecific categories in the species, referred to separate subspecies. The subspecies *garmella* of De Gregorio (1884), was recognized by Friedberg (1934, p. 131) as present in Ukraine and Poland, including specimens from Korytnica (Friedberg 1934, fig. 18; Bałuk and Radwański 1977, pl. 3, fig. 13). This subspecies is characterized by a large size and thick valves. The reference specimen from Humentsi, assigned to this subspecies, is 95 mm long, 62 mm wide and 50 mm thick, and appears to be the largest specimen of all hitherto recorded from the Miocene of Podolia; it is close to specimens from the Vienna Basin (see Schultz 2003, pl. 61, figs 14a, b; pl. 62, figs 1–4 and pl. 63, figs 8a, b) classified as *Chama* (*Psilopus*) *gryphoides gryphoides* Linnaeus, 1758.

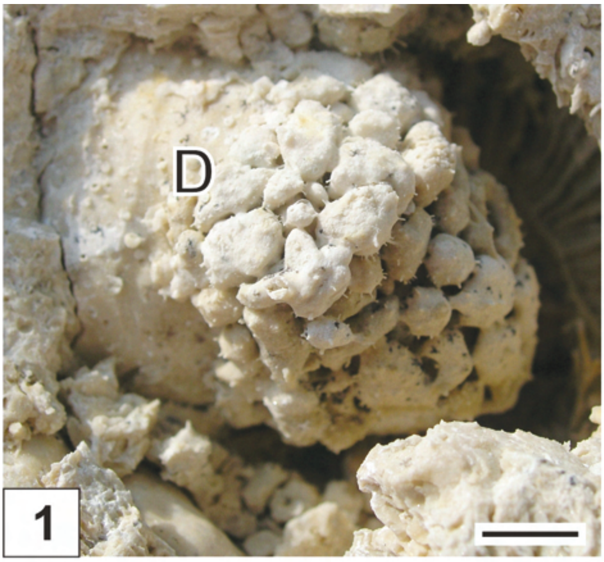
The juveniles of *C. gryphoides* are cemented to the substrate, while the adults rest freely in loose sediment.

During diagenesis, the shells of *C. gryphoides garmella*, due to their thickness, did not undergone complete dissolution, and their fragments survived in some of the balls as the *residual scrolls* (compare Text-fig 3 with Text-figs 5 and 7).

INTERPRETATION OF THE STRUCTURE OF THE ‘*Entobia* BALLS’

The structure of the balls varies from those completely filled by *Entobia*, like a three-dimensional maze, to those displaying more or less numerous residual scrolls of *Chama* shells. The presence and number of scrolls, and the position of the *Entobia* within the balls, depend on the degree of dissolution of the *Chama* shells, and the extent to which they were bored by sponges.

It is not clear whether the *Chama* shells were bored by sponges during, or after, the life of the bivalve. The superficial borings in the outermost layer(s) of the shell could well have been produced when the bivalve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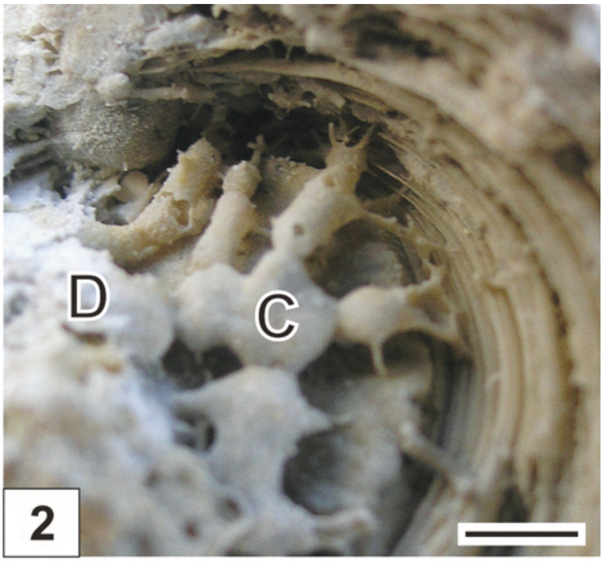
1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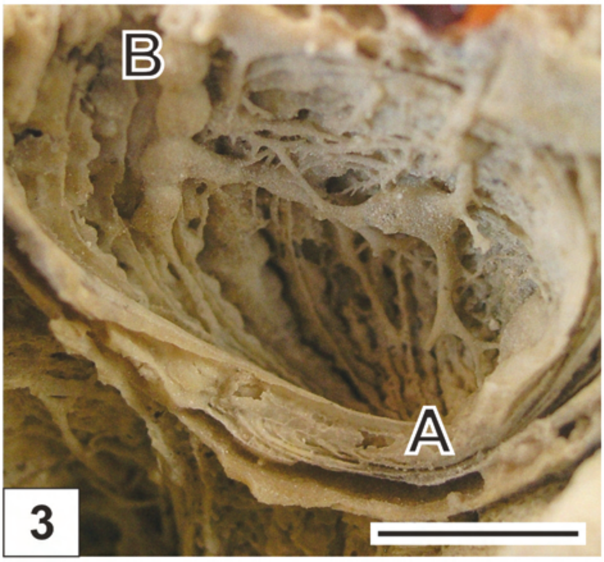
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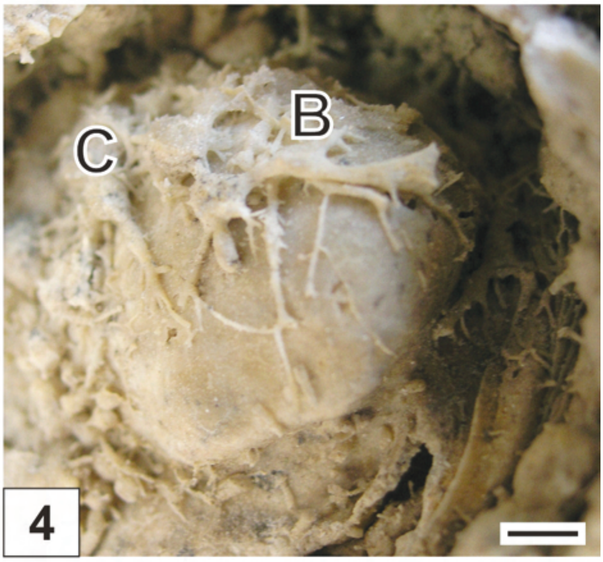
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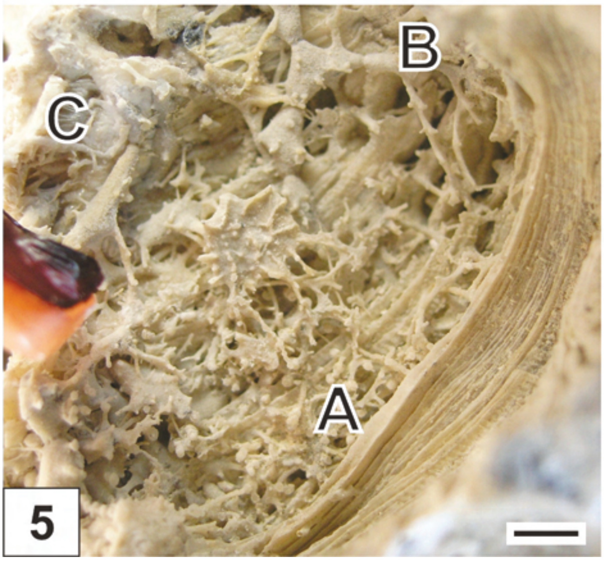
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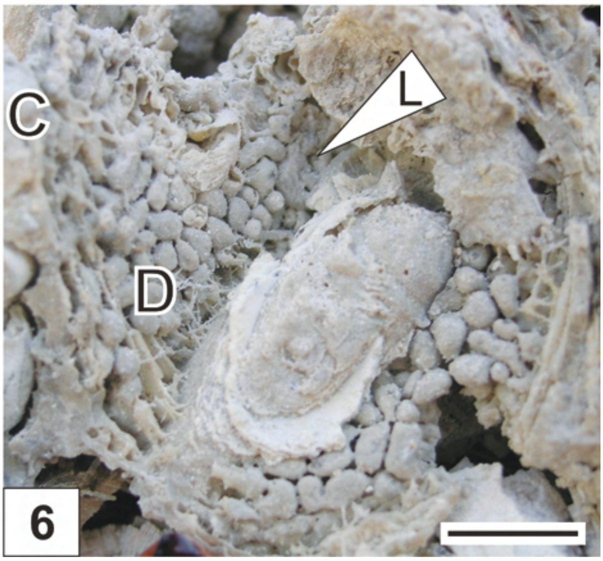
C
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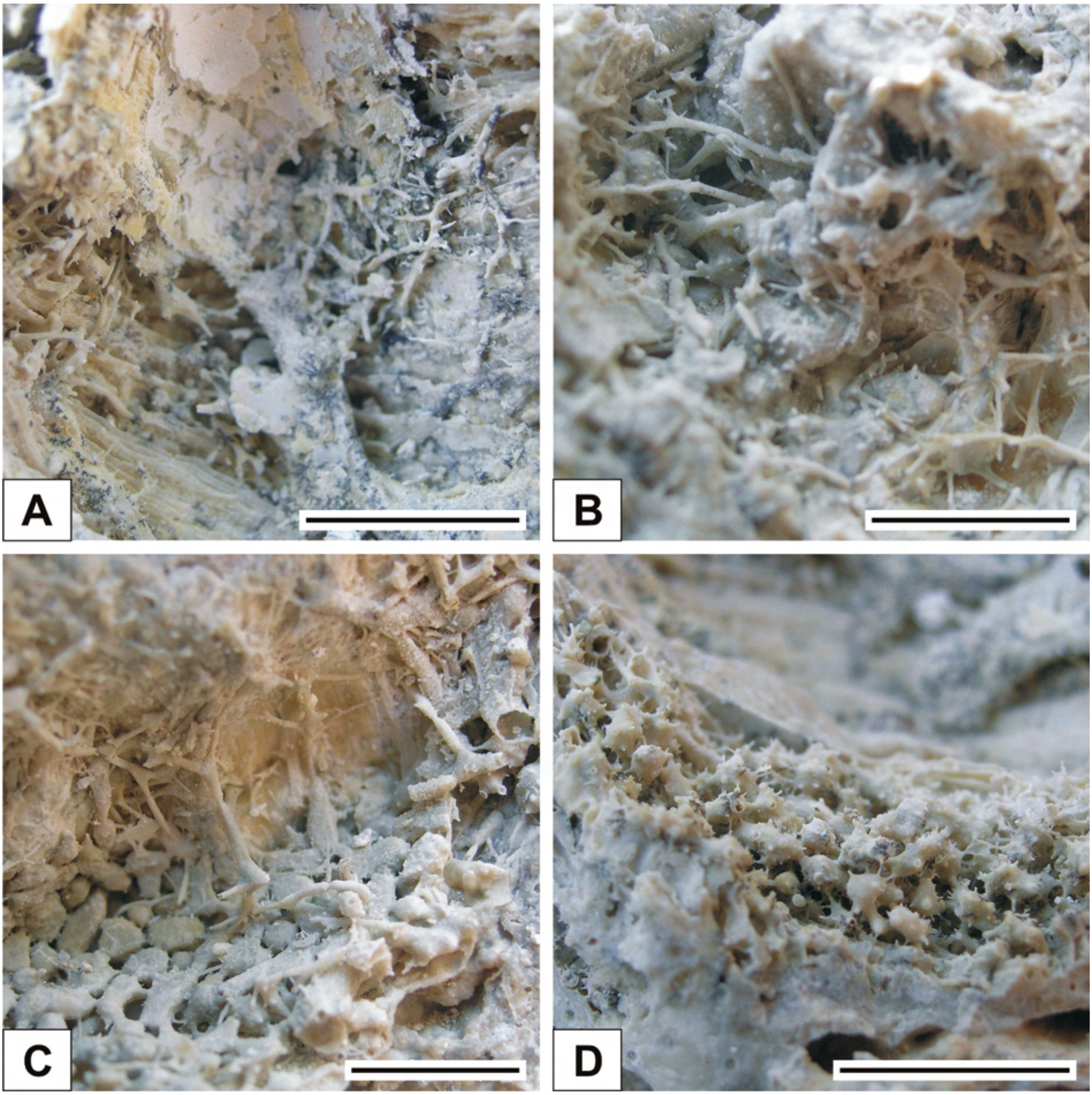
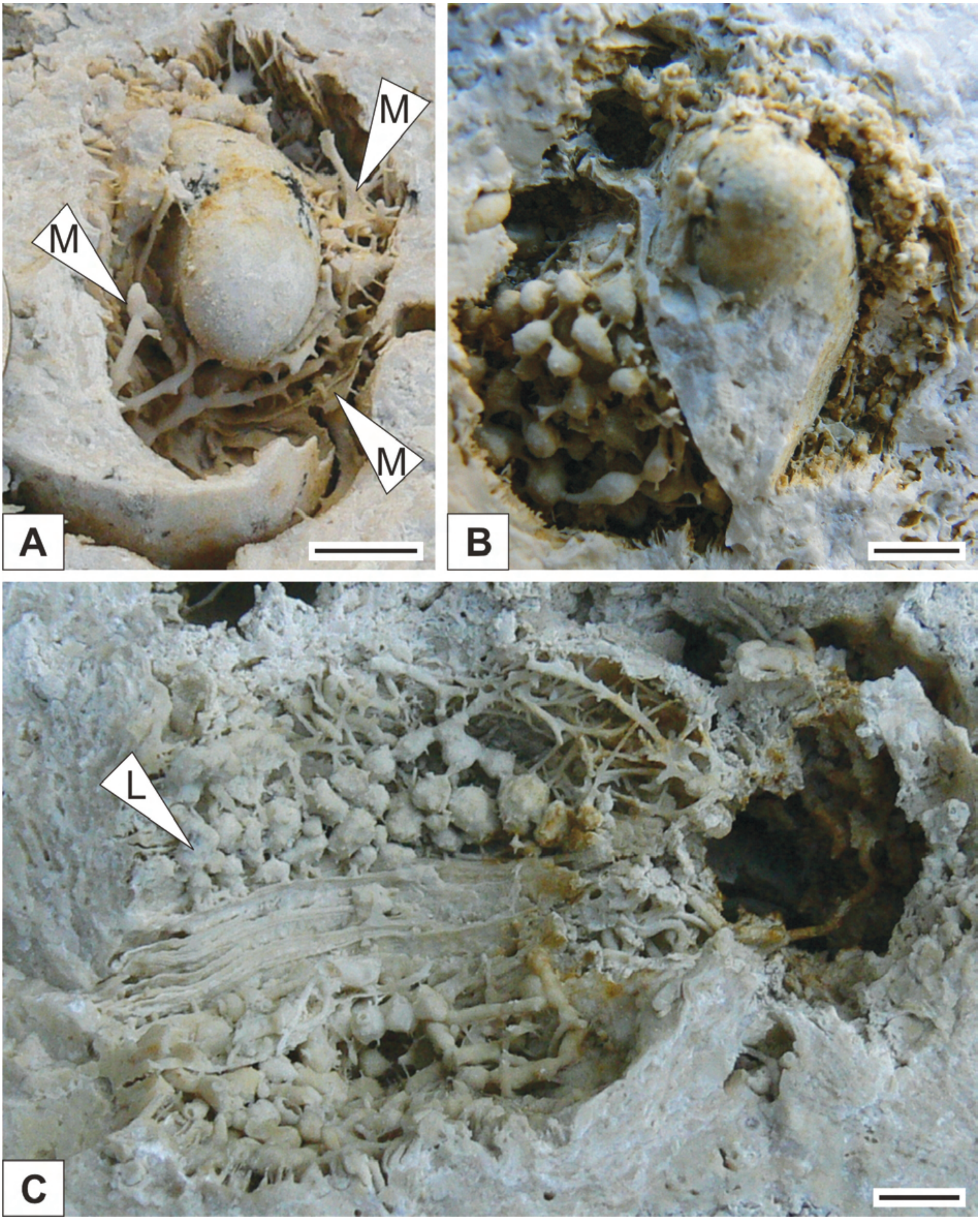
was still alive. This may have been the case with the *Chama* reference specimen, both valves of which were bored patchily on the outer surface (see Text-fig. 3).

The balls in which the *Entobia* borings either transect the scrolls, or adhere to the innermost scroll (see Text-fig. 5/2–5), indicate such extensive damage to



Text-fig. 6. Close-up views (scale bars = 5 mm), to show details of some larger ‘*Entobia* balls’ from Nihyn. **A** – *Entobia cateniformis* Bromley and D’Alessandro (phases **A** and close to **B**); **B** – *Entobia cateniformis* (mostly phase **B**, and some phase **A**); **C** – *Entobia cateniformis* (phases **B**, and **C** close to **D**, with irregular chambers either fused, or connected by very short intercameral canals); **D** – *Entobia geometrica* Bromley and D’Alessandro (phase **D**, with well pronounced intercameral canals and apophyses)

Text-fig. 5. ‘*Entobia* balls’ and their relationship to *Chama* shells, or their residual scrolls, from Nihyn (scale bars = 5 mm); the growth phases of particular ichnospecies are indicated. **1** – *Entobia geometrica* Bromley and D’Alessandro fully developed (phase **D**) and preserved around the steinkern of a completely dissolved *Chama* shell; **2** – *Entobia paradoxa* (Fischer) (phases **C** and **D**) preserved in the innermost part of a *Chama* shell; **3** – *Entobia cateniformis* Bromley and D’Alessandro (phases **A** and **B**) riddling, and adhered to, the innermost layer of a *Chama* shell; **4** – *Entobia cateniformis* (phases **B** and **C**) originally riddling the now dissolved innermost layer of a *Chama* shell, so that it adheres to the steinkern of the shell; **5** – *Entobia cateniformis* (phases **A**, **B**, **C**) completely riddling the whole inner side of a *Chama* shell; **6** – *Entobia geometrica* (phases **C** and **D**) riddling the inner side of a *Chama* shell and avoiding a crypt of *Lithophaga lithophaga*; arrowed (**L**) is a part of the boring morphologically close to *Entobia laquea* Bromley and D’Alessandro



Text-fig. 7. '*Entobia* balls' in/after *Chama* shells (scale bars = 5 mm) from Maksymivka. **A** – *Entobia geometrica* Bromley and D'Alessandro (phases **B** and **C**) associated with the polychaete borings *Maeandropolydora barocca* (**M**) and a crypt of *Gastrochaena* sp.; relicts of a *Chama* shell preserved (at left); **B** – *Entobia geometrica* Bromley and D'Alessandro (phase **D**) and a crypt of *Gastrochaena* sp.; shell of a *Chama* completely removed; **C** – *Entobia geometrica* (all stages) tiering throughout both valves of the large *Chama* shell (anterior view with respect to the bivalve shell, a mould of its interior is left intact by the sponges); arrowed (**L**) is a part morphologically close to *Entobia laquea* Bromley and D'Alessandro (see the text) the bivalve shell that the animal could not have survived. Balls of this type, as well as those bored through completely (see Text-figs 6, 7), should therefore be regarded as resulting from post-mortem drilling of *Chama* shells.

The cases where *Entobia* borings encroach on the surrounding algal structures are consistent with the behaviour of the present-day clionid sponges which may grow over any objects around their colonies (see Warburton 1958, de Groot 1977).

The *Entobia* borings avoid both the bivalve crypts (moulds of borings, see Text-figs 5/6 and 7A, B) and the internal moulds (steinkerns) of the body cavity of the *Chama* shells (see Text-fig. 5/1, 5/4, and 7C). All such moulds, composed of limestone rock, are thus interpreted as having resulted from lithification prior to the settlement of the boring sponges and their subsequent boring into the aragonite shells. The limestone-built structures were not bored by the sponges and remain intact, the sponges thus displaying pronounced substrate selectivity (cf. de Groot 1977, p. 175).

THE *Entobia* ICHNOSPECIES

Although the definition/diagnosis of the ichnogenus *Entobia* Bronn, 1837, as *Borings attributable to sponges of the family Clionidae Gray, 1867*, is clear (see Bromley 1970), the distinction between particular ichnospecies remains less simple, and even vague. It should be noted that the name *Entobia* is applied regardless of the state of preservation: either as empty borings or as moulds formed by passive infilling of borings and their subsequent lithification (see Bromley and D'Alessandro 1984).

In studying the present-day clionid sponges of the rocky limestone shores of the Adriatic it has long been commonly considered (see Volz 1937; de Groot 1977) that the borings are species distinctive. However, further studies have shown (see Rützler and Bromley 1981; Bromley and D'Alessandro 1984; see also Bromley and D'Alessandro 1989) that the morphology of these borings is much more complex. A single boring is composed of a succession of growth phases, from thin exploratory tubules (phase A), through growing chambers (phases B and C), to the final (adult) chamber (phase D), all connected by intercameral canals of variable shapes, and adorned with minute apophyses (see Text-fig. 4). Where the boring takes place in a physically unrestricted environment, the form of the network is described as idiomorphic. On the other hand, where the boring takes place in a physically restricted environment stenomorphic forms develop, constrained by the space available. The *Entobia* under study here are generally idiomorphic due to the great thickness of the *Chama* shells in which they developed. In thin-shelled bivalves, the *Entobia* may become more or less stenomorphic (cf. Bromley and D'Alessandro 1984, fig. 6). It should also be noted that the same species of extant *Cliona* may produce several different *Entobia* ichnospecies which represent behavioural variants related to changes in the environment (see Bromley and D'Alessandro 1989, pp. 296–297).

The following *Entobia* ichnospecies are distinguished in the material studied (see Text-figs 5–7):

> *Entobia geometrica* Bromley and D'Alessandro: characterized by larger chambers, spherical to slightly subangular, connected by relatively distinct intercameral canals, and adorned with numerous apophyses;
>
> *Entobia paradoxa* (O. Fischer): characterized by irregularly shaped chambers, connected with each other directly by snout-shaped protuberances; the exploratory tubules tend to be swollen, as do the relatively scarce apophyses;
>
> *Entobia cateniformis* Bromley and D'Alessandro: characterized by narrow, elongated chambers, connected by indistinct canals or fused together without intercameral canals, may change the direction of growth at right angles, apophyses rare; and
>
> *Entobia laquea* Bromley and D'Alessandro: characterized by densely packed small chambers, spherical to irregular, connected by, or lacking intercameral canals.

Within these *Entobia* ichnospecies, only phases D and C differ clearly from each other. Phase B may usually be distinguished only when conjoined with phases C or D, while phase A remains indistinguishable.

As is apparent from the illustrated specimens (see explanations to Text-fig. 5), the *Entobia* borings from Nihyn are idiomorphic, confined to definite parts of the thick *Chama* shells or to their internal moulds. Those from Maksymivka tend to tier by filling the available space completely, and they avoid the *Gastrochaena* crypts which developed earlier (see Text-fig. 7A, B).

Particular *Entobia* species in the material studied occur separately, and no conjoined/superposed forms were observed, except for some parts of *Entobia geometrica* which are similar (indicated by arrows in Text-figs 5/6 and 7C) to *Entobia laquea*, which most likely may represent a more compressed/compact (? stenomorphic) variety of *Entobia geometrica*.

Particular *Entobia* ichnotaxa are also separate on a regional scale; *E. cateniformis* is dominant at Nihyn (see Text-figs 5, 6) whereas *E. geometrica* is dominant at Maksymivka (see Text-fig. 7).

ENVIRONMENTAL SIGNIFICANCE

According to the relationship between ichno- and zootaxa of the clionid sponges, as recognized by Bromley and D'Alessandro (1989, p. 296, table 1), the ichnotaxa present in the '*Entobia* balls' correspond to two species of extant clionids, *Cliona vastifica* Hancock, 1849, and *Cliona celata*, Grant, 1826.

These two species have long been known (see Volz 1939; Hartman 1957; de Groot 1977) to inhabit the rocky substrates in the shallowest parts of the shore: *C. vastifica* ranging from lower intertidal to shallow subtidal, and *C. celata* extending up to tidal pools; in loose shell material they spread down to infralittoral depths (see Hartman 1957, fig. 1). This agrees well with the environmental interpretation of the Medobory Biohermal Complex as outlined above. Consequently, the ubiquity of '*Entobia* balls' in some parts of the sequence exposed at the Nihyn Quarry indicates longer period of lowstand there, enabling the development of what is distinguished as the *Entobia* ichnofacies (see de Gibert *et al*. 1998).

Under such conditions, the relatively large bivalves, *Chama gryphoides garmella*, are presumed to have rested in, or amidst, the algal structure. The dissolution of their shells evidently took place when the clionid and gastrochaenid borings had been completely lithified by early diagenetic processes.

The advanced diagenesis (both early lithification, and dissolution of aragonite), as well as the general rarity of boring sponges, distinguish the Middle Miocene (Badenian) facies of Ukraine from those of Poland, where the same two species of clionid sponges profusely riddled both the ancient rocky shore and all detrital or biogenic materials; their borings have remained empty, and were classified in the zoological nomenclature (Radwański 1964, 1969, 1970, 1977; Bałuk and Radwański 1977), as recently accepted by Finks and Rigby (2003, p. 282).

CONCLUDING REMARKS

Both the Miocene borings studied from western Ukraine as well as those discussed by Bromley and D'Alessandro (1984) allow the inference to be made that the shape of particular ichnospecies of the ichnogenus *Entobia* is dependent, partly at least, upon external conditions. These comprise not only the lithology of the substrate (see de Groot 1977) but also physical parameters such as water temperature and chemistry (salinity) in ambient, very nearshore waters such as those of the Medobory Biohermal Complex. It is thus assumed that these features would have to be taken into account in investigations of any ancient clionid sponge borings.

The two species of the boring sponge *Cliona*, inferred from the *Entobia* ichnotaxa recognized in the material studied, tended to occur separately throughout the Medobory Biohermal Complex, *Cliona vastifica* dominating at Nihyn, and *Cliona celata* at Maksymivka. A similar case was documented from the coeval rocky shore zone in the Holy Cross Mountains, Poland, where the same two species had bored separately (see Radwański 1969, 1970). This agrees well with the present-day distribution of clionid sponges in the Mediterranean where, for example, the clionid assemblages of the Adriatic (see Volz 1939; Hartman 1957; de Groot 1977) differ from those of the island of Rhodes (see Rützler and Bromley 1981).

The last of the above conclusions is also relevant to the clionid borings in the *Chama* shell from Humentsi, the reference specimen for the '*Entobia* balls' studied. All the borings (see cb in Text-fig 3A–D) are empty, having probably been preserved exactly as they were left after the death of the boring sponge. The irregularly angular shape of their chambers corresponds to that of the present-day species *Cliona viridis* (O. Schmidt, 1862) from the shores of the Adriatic (see Volz 1939, pl. 2, fig. 4 and pl. 4, fig. 2), and from the only ancient case in the coeval Holy Cross shore zone in Poland (see Radwański 1969, pp. 10, 11 and pl. 3, fig. 2). Such borings do not as yet have any precise counterparts in the ichnological taxonomy ("Entobian A" in Bromley and D'Alessandro 1989, table 1). Nevertheless, the inferred occurrence of the species *Cliona viridis* at Humentsi illustrates well both the species variability and the regional diversity of clionid sponges throughout the Medobory Biohermal Complex of western Ukraine.

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