Microbial boring activity in the Jurassic, Cretaceous and Tertiary limestones of the Western Carpathians

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Abstract. Microborings from bioclasts were selected and studied from several hundred thin sections of Mesozoic and Tertiary limestones. They were produced by cyanophyta, algae and fungi. Nine morphotypes were discerned especially from bivalves, crinoids, foraminifers; microborings from coralline algae and *Ethelia alba* were also preliminarily studied. The boring activity continued until the diagenetic stage. The cases of redeposition of terrestric microborings in the marine environment and retransportation of microborings from shallow marine waters to the deep water were considered. The density of microborings is proportional to the time of their exposition on the bottom, then to the rising of the sea-level and interruption of the transport from the sea-shore.

Key words: Jurassic, Cretaceous, Tertiary, Western Carpathians, microborings, diagenesis.

1. Introduction

Thin sections of limestones reveal very frequently thin channels of boring microorganisms in the skeletal fragments. In our collection they were abundant especially in pelecypod shells within the red Liassic limestones. They are well visible due to their filling by Fe-oxides and hydroxides. Microborings are especially dense in the hardgrounds where they affected not only fossils but also the lithified sediment. Microborings are common also in the skeletal parts of ammonites, belemnites, brachiopod shells, echinoderm ossicles, bryozoans and foraminifers. In the Tertiary limestones they perforate skeletal remains of algae like Corallinaceae and *Ethelia alba* what will be illustrated here.

Microorganisms produce their tiny tunnels by dissolution. The purpose of boring is protection and alimentation (organic matter contained in the skeletal particles). Microborings were defined by the span of the tunnel diameters from 1 μm to 100 μm. Therefore, borings of the worm *Potamilla*, sponge *Cliona* or traces of Cirripedia on the belemnite rostra should not be included here. Microborings are produced by Procaryota (cyanophytes/cyanobacteria) and also by Eucaryota like Chlorophyta, Rhodophyta and Fungi.

Repetition of some characteristic patterns of microborings is evidently produced by the same taxon. The key to their understanding is the study of recent microborings. The fossils are embedded by the resin and then the specimen is dissolved by an acid. Such artificial casts are studied using electron microscope (Golubic et al., 1970). According to our opinion this method should be completed by the study of these microborings in thin sections what will be documented here.

By comparison with recent endoliths it is necessary to take into account that the ancient fossils could contain also several died-out species of microendoliths. Glaub (1994) distinguished 34 ichnotaxa in 500 samples of Jurassic brachiopod and mollusc shells from different European basins. About 70 % of them show similarities with the modern microendoliths and 30 % have no analogy.

The type of tunnel is directed by the instinct mediated through the genus. There are some analogies with the manifold patterns of corridors bored in the tree by beetles or fucoids produced by worms. Seilacher (1967) compared the behaviour of a limnivore animal *Helmintoida labyrinthica* with the computer programme which renders the best possible extraction of nutrients. The programme contains four commands: 1. Move horizontally keeping within the single bed of sediment. 2. After advancing one unit of length make a U-turn. The length of the worm could serve as a measuring rod. 3. Always keep in touch with your own or some other tunnel (chemotaxis). 4. Never come closer to any other tunnel than the given distance „d“ (phobotaxix) what prevents uneconomical crossing of tunnels.

2. Application of microborings in the facies studies

Glaub (1999) used microborings for the paleobathymetric reconstruction. From the samples of Jurassic limestones she discerned four zones according to the intensity of light:

1) Shallow euphotic zone II with *Fasciculus acinosus*/*F. dactylus* ichnocoenosis. Cyanobacteria/Cyanophyta (Procaryota) prevail there. The borings are perpendicular to the surface of the substratum.

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2) Shallow euphotic zone III with the ichnocoenosis *Fasciculus dactylus/Paleoconchocelis starmarchii* corresponding to the well illuminated part of subtidal environment. Besides mentioned microborings of Protista it contains also borings of chlorophyta and rhodophyta (Eucaryota).

3) Deep euphotic zone with *Reticulina elegans* and *Reticulina* sp. 1 with *Paleoconchocelis starmarchii* representing poor illuminated parts of subtidal environment (the intensity of light lowered to 1–10 % of the surface light. It contains eucaryote endoliths, especially of chlorophyta. The borings parallel to the substratum are dominant.

4) Aphotic zone with *Saccomorpha clava/Orthogonum lineare*. The ichnotaxa are similar to the recent chemoheterotrophic endoliths (e.g. fungi).

Olóriz et al. (2004) studied the relations among the microborings abundance of encrustation and the degree of fragmentation of skeletal remains in the Oxfordian limestones (Prebetic Zone of Spain). They discerned only two groups: simple and branching microborings. They found a higher index of microborings (MB_i) on the ammonites and serpulids. Lower occurrence of microborings had ostracodes, microforaminifers, bivalves, gastropods and echinoderms. There was a direct relationship between the index of microborings (MB_i) and the index of encrustation (E_I). No relation to the index of fragmentation was proved. Intervals with higher MB_i and E_I corresponded to the periods of transgressive systems tract (TST), than to the periods of the growing distality.

3. Microboring morphotypes

In the following text we will try to catalogue well defined types of microborings from the numerous thin sections of limestones mostly in Liassic bivalves.

Morphotypes:
A – almost straight tunnels parallel with the surface of bioclasts (e.g. Pl. IX. Fig. 4).
B – undulating microborings (Pl. I. Fig. 1; Pl. VI. Fig. 4).
C – dichothom branching under the acute angle (Pl. IX, Figs. 1 and 2).
D – rectangular branching (Pl. I. Fig. 3).
E – stellate groups of tunnels (Pl. I. Figs. 3 and 5).
F – zig–zig microborings (Pl. I. Fig. 2)
G – cup-like borings (Pl. III. Figs. 1-3)
H – polygonal net-like borings (Pl. IV. Figs. 1 and 3; Pl. X. Figs. 1-3).
J – very thin borings perpendicular to the surface of the skelet (Pl. II. Fig. 7).

Similar essay concerning the definition of the morphotypes was carried out by Böhm et al., 1999 (p. 204 and Pl. 23, Figs. 3–9). They discerned following three morphotypes:

Morphotype 1 – "spotted" – dark dots circular and elliptical with a diameter about 0.32 mm. They are associated with smaller borings with a diameter of about 0.06–0.08 mm.

Morphotype 2 – straight or meandering unbranched borings with a diameter about 0.03 mm.

Morphotype 3 – covers the branched forms with three subtypes of branching: a) dichothom (ϴ 0.03–0.05 mm), b) rectangular (ϴ 0.06–0.08mm), c) zig-zag (ϴ 0.016–0.025 mm).

These types were, however, poorly illustrated. On the Pl. 23, Figs. 4 and 5 there is a faulty explication "unbranched, elongated", meanwhile the microborings are clearly branched.

4. Bivalves

Perhaps, the most frequent microendoliths occur in the bivalvian fragments. Bivalves construct their shells from the calcite or aragonite. During the diagenesis aragonite shells are dissolved and replaced by fine-grained secondary calcite. Traces of microendoliths may be preserved in them. Aragonite shells are rarely replaced by calcite mosaic recrystallized "in situ". Up till now we did not succeed to find relicts of microendoliths in them.

The most frequent type of microborings is **undulated and simultaneously branched** (Pl. I. Fig. 1). Extreme types are **zig-zag tunnels** (Pl. I. Fig. 2). Interesting types are **rectangular branching** (Pl. I. Figs. 3-4) and **stellate aggregates** (Pl. I. Figs. 3 and 5). Very dense concentration of microendoliths is typical for bioclast accumulations exposed on the bottom for a long time (condensed sedimentation, Pl. I. Fig. 6). Another type represents thicker tunnels with the **club-like branching** (Pl. II. Fig. 1) corresponding to siphonate green algae. **Barrel-like borings** (Pl. II. Fig. 2) with a characteristic articulation correspond to the microendolith *Fasciculus dactylus* Radtke 1991. They were produced by cyanophyta in the euphotic zone (Glaub, 1998). Traces of borings in the thick shells of rudists (Pl. II. Fig. 3) were evidently produced by metazoans and will be not included in our study.

Bivalves with original aragonitic shell were filled after their dissolution by fine-grained pseudosparite. Microborings may be preserved in them like ghosts (Pl. II. Fig. 5-6). Remnants of tunnels are sometimes bordered by Fe-oxides (Pl. II. Fig. 4).

Fragments of bivalves, perforated perpendicularly to the surface of the shell by very tiny straight fungal microborings (Pl. II. Fig. 7) were rarely found.

5. Foraminifers

Lenticulina. Characteristic microendoliths resembling the tiny "cups" densely ranged were found on the numerous specimens of *Lenticulina* (Pl. III. Figs. 1-4). They begin from the outside by a narrow neck and end by a cup with elliptical to circular cross section. They can be identified with *Cavernula zancobola* Schmidt 1992. Glaub (1994, p. 73, Tab. I. Fig. 3) described them as globular spheroids with a diameter 10 μm. The contact with surface forms a thin corridor (only 1–3 μm) perpendicular to the surface. Glaub (l. c.) cited this taxon from the brachiopod shells of the Kimmeridgian and Tithonian age. One of our specimens (Pl. III. Fig. 4) displays even triangular cross-sections. Maybe it represents another species of that genus. Some thicker borings with irregularly changing diameter were associated with them (Pl. III. Fig. 2).

Large foraminifera. Rotalids often display the characteristic **net-like microendoliths** (Pl. IV. Fig. 1). A case of tiny corridors forming a tight spiral occurred (Pl. IV. Fig. 2). Thicker corridors with irregularly branched patterns were found in nummulites and discocyclinas (Pl. IV. Figs. 3–5).

6. Crinoids

The crinoidal ossicles from the red crinoidal limestones frequently contain thicker, slightly undulated tunnels (Pl. V. Figs. 1-2). Their oscillating thickness is due to the undulations in the plane different from that of the thin section.

A rare stellate form with club-shaped ends of the "rays" is reproduced in the Pl. V. Fig. 3. Perkins and Halsey (1971, Fig. 11) described a similar endolith as a stellate growing form of green algae. Our Pl. V. Fig. 4 shows a tunnel penetrating already in the syntaxial rim formed during the diagenesis (see the twinning lamellae continuing from the crinoidal plate into the rim). The echinoderm plate on the Pl. VI. Fig. 2 contains various thin, mutually crossing microborings. In the sample Pl. VI. Fig. 1 they form an imperfect network. Peculiar traces bitten into periphery of pentagonal columnalium are visible on the Pl. VI. Fig. 3. It contains also some smaller circular microborings.

The cherts in crinoidal limestones contain abundant ghosts of microborings in the entirely silicified plates. They are filled by Fe-oxides (Pl. V. Figs. 4 and 5). The illustrated cases proceeded from the allodapic intercalations (calciturbidites) in the Berriasian–Valanginian pelagic limestones. The tunnels are thin and undulated. The boring activity took place in the shallow zone before the transport of the biodetritus into the deep water.

7. Algae

Corallinaceae – were studied from the thin sections of Paleocene and Miocene limestones. They contain larger holes, sometimes in peculiar groups filled by sparite, probably bored by metazoans (Pl. VII. Figs. 1-6). Their ends are sometimes thinned (Pl. VII. Figs. 5 and 6). Larger, elongated and elliptical holes are filled partly by micrite (Pl. VIII. Fig. 1). Circular traces with dark borders (Pl. VIII. Fig. 2) and thin straight microborings with haphazard orientation are rare (Pl. VIII. Fig. 3). In a tunnel, five sickle-like partition was found (Pl. VIII. Fig.4); it reflects probably the progressing of the boring. The specimen illustrated in the Pl. VIII. Fig. 5 proves that the boring activity continued in the diagenetic stage (the microboring penetrated from the lithified sediment into the algae).

Ethelia alba is another alga frequently attacked by boring organisms. Dichothomically branched fan-like tunnels with faint articulation reflecting the stages of progress were present at two localities (Pl. IX. Figs. 1 and 2). Interesting phenomenon is a group of microendoliths which are subparallel in spite of considerable mutual distances (Pl. IX. Fig. 3). The Pl. IX. Fig. 4 displays a long, slightly undulated tunnel passing through the centre of the thallus (Pl. IX. Fig. 4). The course of the tunnel is not accommodated to the course of algal fibres.

8. Some examples of microborings in bryozoans, belemnites and ammonites

The sample of a bryozoan contains tunnels of various diameter perpendicular to the bioclast surface (Pl. X. Fig. 5). The belemnite rostrum (Pl. X. Fig. 6) is penetrated by small circular holes, a part of them belongs to the microborings parallel with the surface rostrum.

The aragonite shell of ammonite succumbed to the rare spot-like dissolution in several stages (Pl. XI. Figs. 1 and 2). The openings formed by the dissolution were filled by sparite and then, already in diagenetic stage, bored by tiny tunnels (Pl. XI. Fig. 1).

9. Peculiar types of microborings in the bioclasts of an unknown appurtenance

The borings of the genus *Dictyoporus* Mägdefrau in the *Orbitolina*-bearing Cenomanian limestones (an exotic pebble) resemble a net with pentagonal openings (Pl. X. Figs. 1-3).

Tiny tunnels forming a net with "knots" occurred in a silicified distal turbidite (Pl. X. Fig. 4) amidst the radiolarites, they were transported into the deep-water sediment.

10. Comparison with the terrestric microborings

Rocky surface covered by lichens is usually penetrated by straight, very thin tunnels of cyanophyta (Pl. XI. Fig. 3). Sometimes they occur in thin sections of limestones as artefacts from the contamination, if the sample was collected with negligence. If such microborings are limited to one clast only, the redeposition of a terrestric fragment in the marine environment may be admitted (Pl. XI. Fig. 4).

11. Some aspects connected with microborings

Microboring activity continues sometimes still in the diagenetic stage. They occur also in bioclasts which were evidently not loose but occurred already in the solidified sediment. On the Pl. VIII. Fig. 5 it can be seen that the microboring organism penetrated in the coralline alga from the solidified sediment. Microborings from the advanced diagenetic stage in the voids filled by sparite in the dissolved aragonite shell of ammonite were already mentioned (Pl. XI. Figs. 1-2). Peculiar microborings in the sparitic cement can be seen on the Pl. X. Fig. 7.

Microendoliths are preserved and expressed in chert nodules due to their filling by Fe-oxides even in the case that their silicified bioclasts totally disappeared from thin section (Pl. I. Fig. 3; Pl. VI. Fig. 5).

Redeposition of the microborings to the deep-water environment. Microendoliths originated in the shallow marine water were sometimes transported to the deep water and occur within the turbidite intercalations (Pl. VI. Figs. 4-6). Typical case of distal turbidite with bored bioclasts amidst the radiolarites was already mentioned (Pl. X. Fig. 4).

The possibility of redeposition of clasts with terrestric microborings into shallow marine environment is supposed in Fig. XI. Fig. 4.

The abundance of the borings is proportional to the length of time during which the bioclasts were exposed on the sea bottom. Their accumulation is interpreted in terms of sequence stratigraphy as a period of deepening (rising of the sea-level) and the interruption of the transport from the shore (Óloriz et al., 2004). The extreme density of microborings is in the hardgrounds from the periods of growing distality.

12. Conclusion

Cyanophyta/cyanobacteria, algae and fungi produced microborings in bioclasts (shells) for shelter and nutrients (aminoacids). The microborings are distinguished by somewhat different patterns dictated by the genetic inheritance. Some selected examples of microborings from bivalves, crinoids, foraminifers and algae are illustrated. Preliminary nine morphotypes except for algae were discerned. Two species: *Fasciculus dentatus* Radtke (in bivalve) and *Cavernula zancobola* Schmidt (in *Lenticulina*) were identified.

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References

Böhm, F., Ebli, O., Krystyn, L., Lobitzer, H., Rakús, M. & Siblík, M., 1999: Fauna, stratigraphy and depositional environment of the Hettangian – Sinemurian (Early Jurassic) of Adnet (Salzburg, Austria). Abhandlungen Geol. Bundesantalt, Bd. 56, 2., 143–271.

Glaub, I., 1994: Mikroborspuren in ausgewählten Ablagerungsbereichen des europäischen Jura und Unterkreide (Klassifikation und Palökologie). Courier Forschungsinstitut Senckenberg 174, 1–324.

Glaub, I. 1999: Paleobathymetric reconstructions and fossil microborings. Bull. Geol. Soc. Denmark, 45, 143–146.

Golubic, S., Brent, G. & Le Campion, T., 1970: Scanning electron microscopy of endolithic algae and fungi using a multipurpose casting embedding technique. Lethaia, 3., 203–209.

Olóriz, F., Reolid, M. & Rodríguez-Tovar, F. J., 2004: Microboring and taphonomy in Middle Oxfordian to Lowermost Kimmeridgian (Upper Jurassic) from the Prebetic Zone (southern Iberia). Paleogeography, Palaeoclimatology, Palaeoecology , 212, 181-197.

Perkins, R. D. & Halsey, S. D., 1971: Geologic significance of microboring Fungi and Algae in Carolina shelf sediments. Journ. Sedim. Petrography vol. 41, No. 3, 843–853.

Radtke, G., Hofman, K. & Golubic S., 1997: A bibliographic overview of micro- and macroscopic bioerosion. Courier Forschungsinstitut Senckenberg 201, 307–340.

Seilacher, A., 1967: Fossil behavior. Scientific American 217, 2, 72–80.

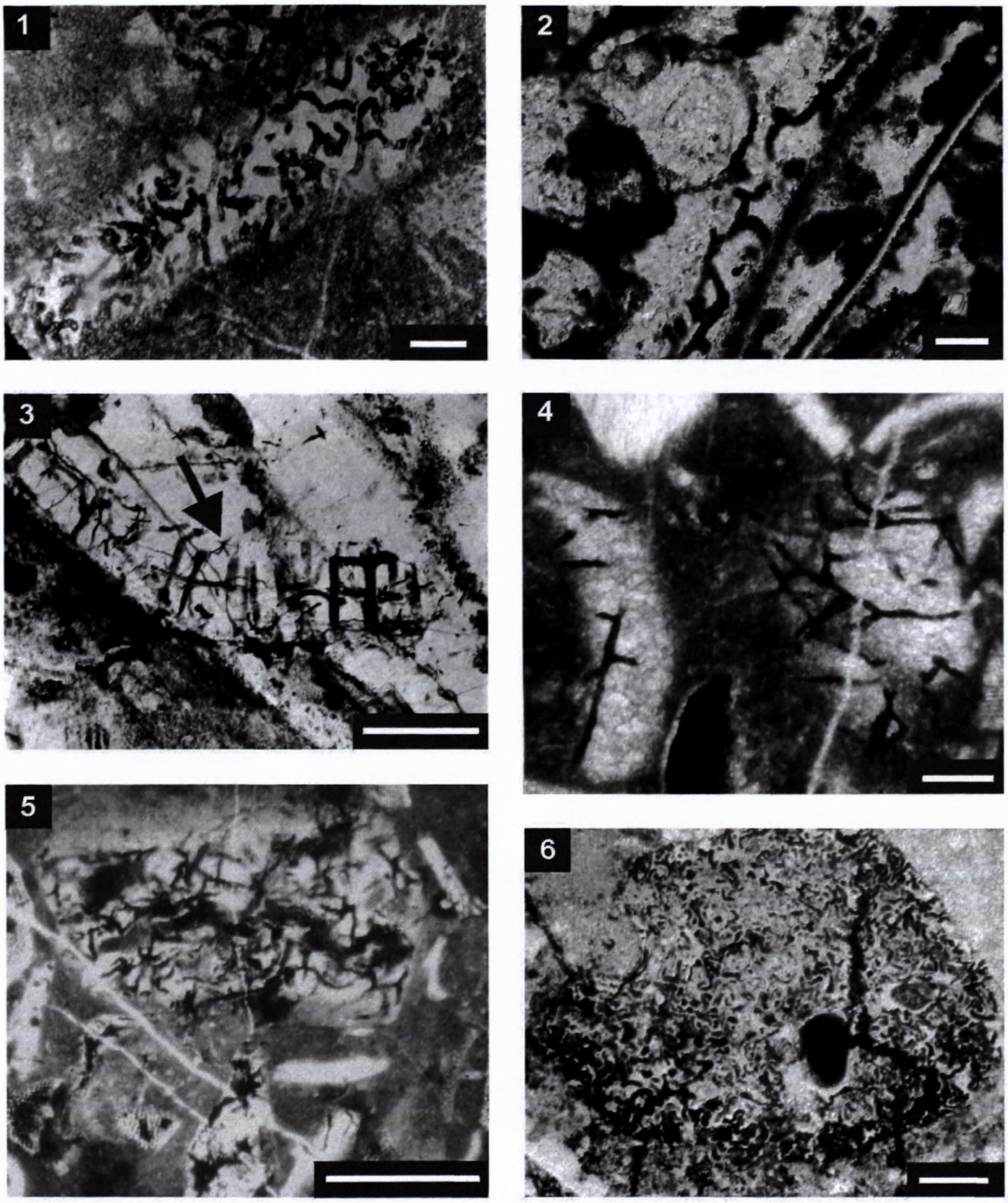

Plate I.

Fig. 1. Undulated and branched microendoliths in bivalve, filled by Fe-hydroxides. Liassic limestone with *Involutina liassica*. Krížna nappe, Donovaly, Veľká Fatra Mts. Scale bar = 20 μm.

Fig. 2. Microboring of "zig-zag" type in bivalvian clasts; tunnels filled by Fe-hydroxides. Callovian limestone, Czorsztyn succession of the Pieniny Klippen belt, Mikušovce. Scale bar = 100 μm.

Fig. 3. Two types of microborings in the silicified bivalvian shell: thicker rectangular and thin stellate tunnels (arrow). Red chert in red crinoidal limestones of Liassic age, Choč nappe, between Pružina and Predhorie, Strážovské vrchy Mts. Scale bar = 100 μm.

Fig. 4. Rectangular branching of microborings. Red Toarcian limestone, Solisko near Donovaly, Nízke Tatry Mts. Scale bar = 20 μm.

Fig. 5. Stellate arrangement of microendoliths in the bivalve shell of the Fe-hardground. The same locality as in Fig. 4. Scale bar = 100 μm.

Fig. 6. Microendoliths in a bioclast from the Fe-Mn hardground. Toarcian, Choč nappe, quarry near Bzince, Čachtické Karpaty Mts. Scale bar = 20 μm.

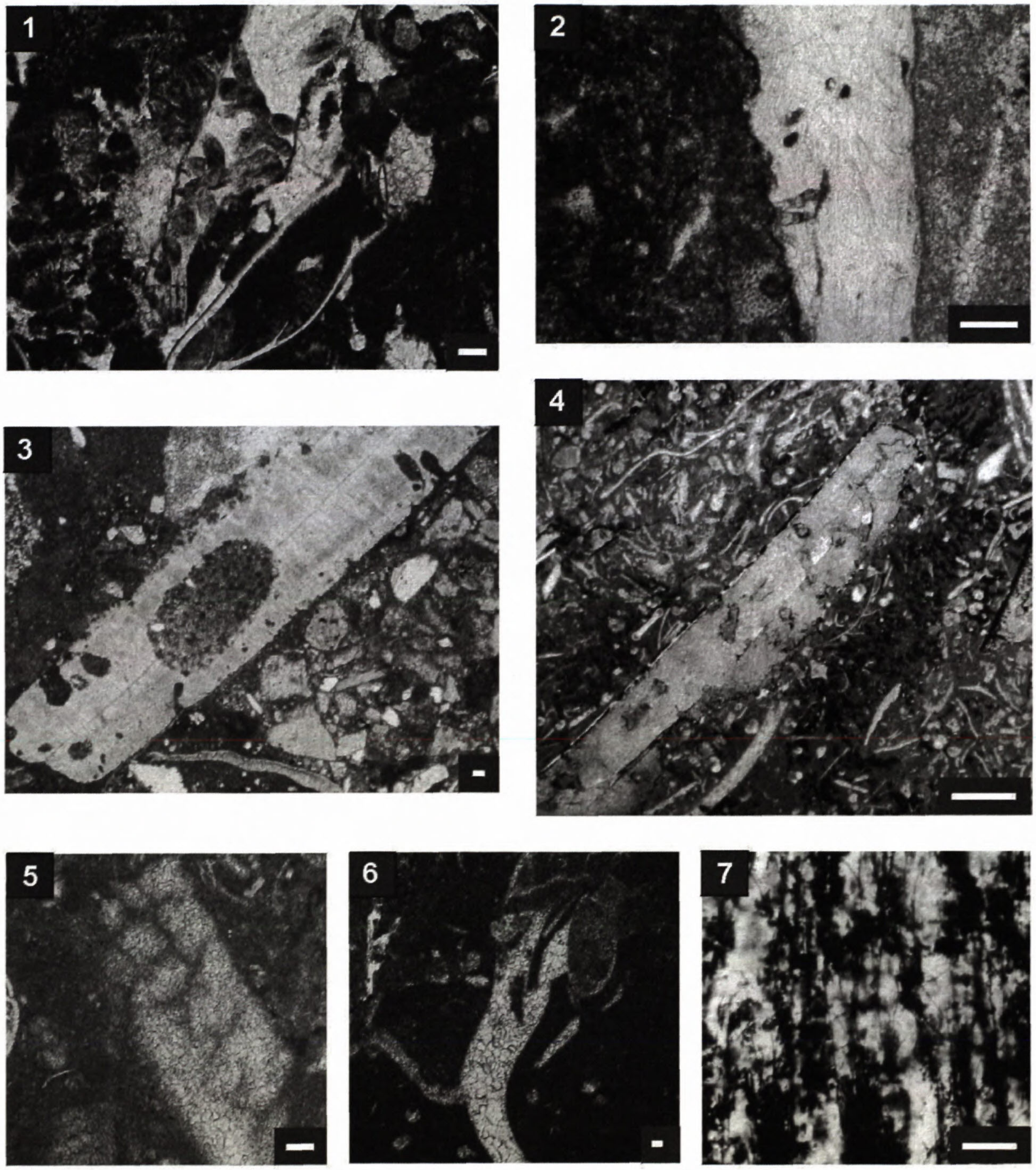

Plate II.

Fig. 1. Club-shape branched microendoliths from siphonate green algae in a bivalve. Upper Lotharingian limestone, Choč nappe, Chtelnica, Čachtické Karpaty Mts. Scale bar = 100 μm.

Fig. 2. "Barrel-like" microboring of *Fasciculus dactylus* in a bivalve. According to Glaub (1998) it is a sign of shallow euphotic zone III. Toarcian limestone, Krížna nappe, Horná Turecká, Veľká Fatra Mts. Scale bar = 20 μm.

Fig. 3. Two types of microborings in a bivalvian shell. Senonian limestone, Zemianska Dedina, Orava. Scale bar = 100 μm.

Fig. 4. Corroded aragonite bivalve with Mn-Fe coating have been filled after dissolution by fine-grained sparite. Borings after perforating organisms have been preserved to their early filling by calcite mud. Upper Kimmeridgian – Lower Tithonian of the Czorsztyn Unit. Kyjov – Pusté Pole. Scale bar = 100 μm.

Fig. 5. Bivalve shell originally composed of aragonite was filled by fine-grained calcite aggregate. Corridors of the boring organism preserved as ghosts. Kambühel limestone, Paleocene, settlement Rovná, Brezovské Karpaty Mts. Scale bar = 100 μm.

Fig. 6. Originally aragonite shell filled by fine-grained calcite aggregate contains relicts after the boring organisms. Upper Berriasian limestone, Czorsztyn Unit, Ďurčova valley near Stará Turá, Čachtické Karpaty Mts. Scale bar = 100 μm.

Fig. 7. Tiny tunnels bored by fungi in a bivalve shell. Mn-hardground. Lower Tithonian limestone, Czorsztyn Unit, klippe of Vršatec castle. Scale bar = 20 μm.

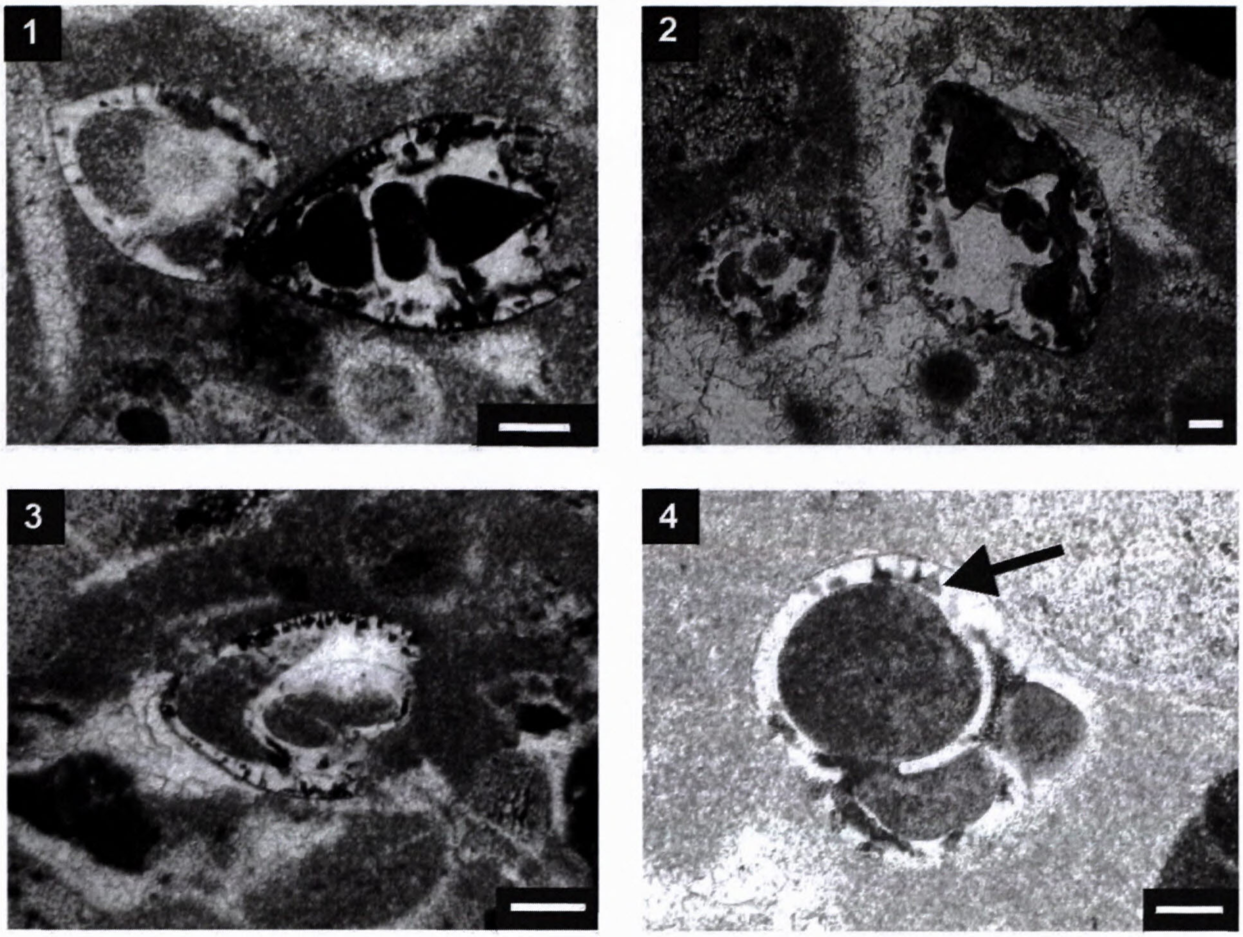

Plate III.

Figs. 1 and 2. Spheroidal microborings in the test of *Lenticulina* conformable to *Cavernula zancobola* Schmidt, 1922. Neocomian limestone, Czorsztyn Succession, quarry Dolný Mlyn near Lubina, Čachtické Karpaty Mts. Scale bar = 20 μm.
Fig. 3. Tiny sections of *Cavernula zancobola* with thick club-like borings probably from siphonate green algae. Neocomian limestone, Czorsztyn Succession, quarry Dolný Mlyn near Lubina, Čachtické Karpaty Mts. Scale bar = 100 μm.
Fig. 4. Microborings of *Cavernula* type; probably new species with triangular section. Locality as in the figs. mentioned above. Scale bar = 100 μm.

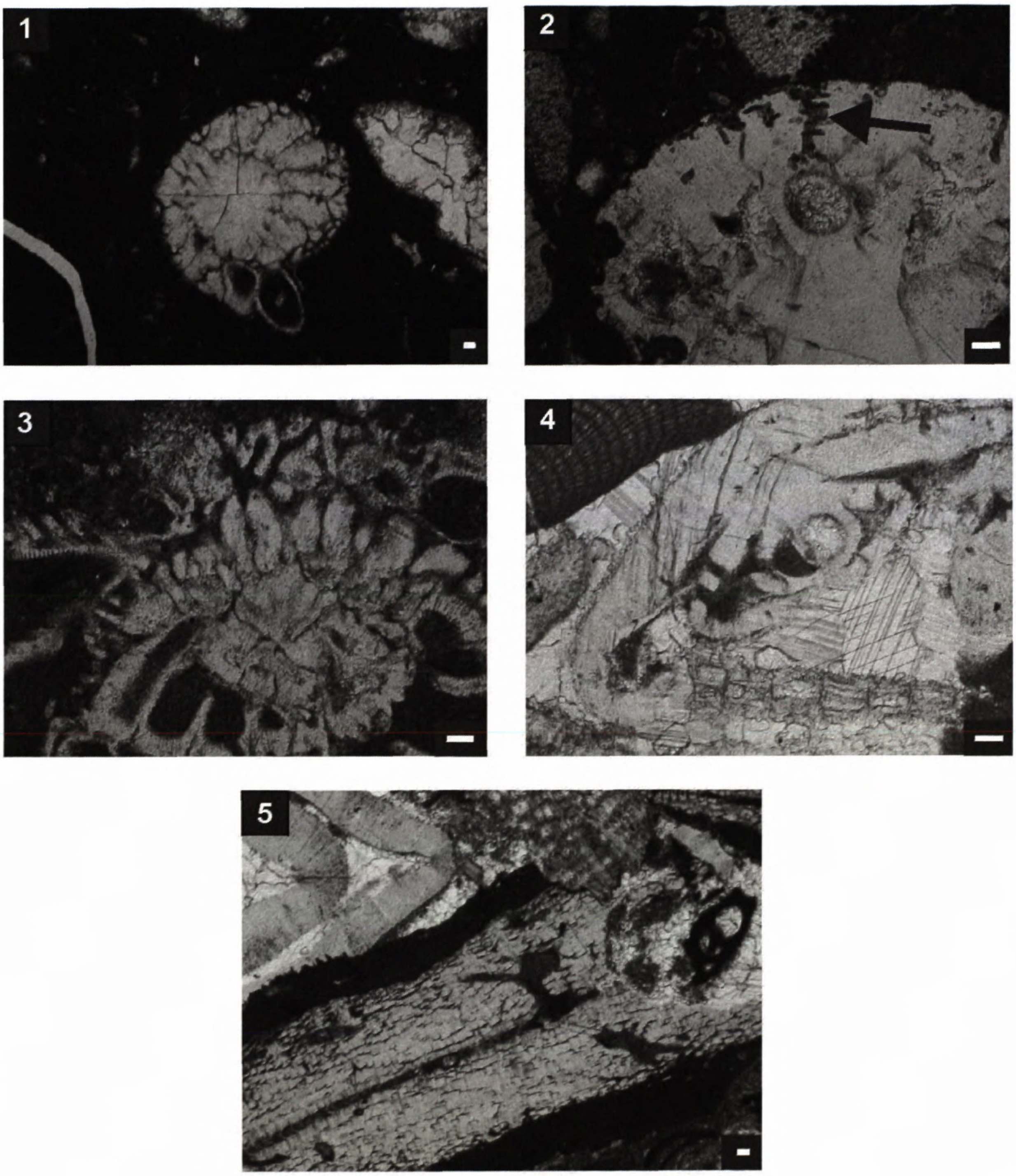

Plate IV.

Fig. 1. Net like microendoliths in *Rotalia*. Kambühel limestone, Paleocene, Ladziny, Brezovské Karpaty Mts.
Fig. 2. Tiny spiral microborings in a larger foraminifera. The same locality as in Fig. 1.
Fig. 3. Group of corridors in the test of *Rotalia*, Kambühel limestone, Paleocene, Rúbanice near Ovčiarske, Middle Váh valley.
Fig. 4. Microborings partly rectangular in the *Nummulites* test. Paleogene limestone, Ježov hill, Oravice.
Fig. 5. Microborings in the test of *Discocyclina*. Paleogene limestone. Bratancov stream near Žilina.
Scale bars = 100 μm.

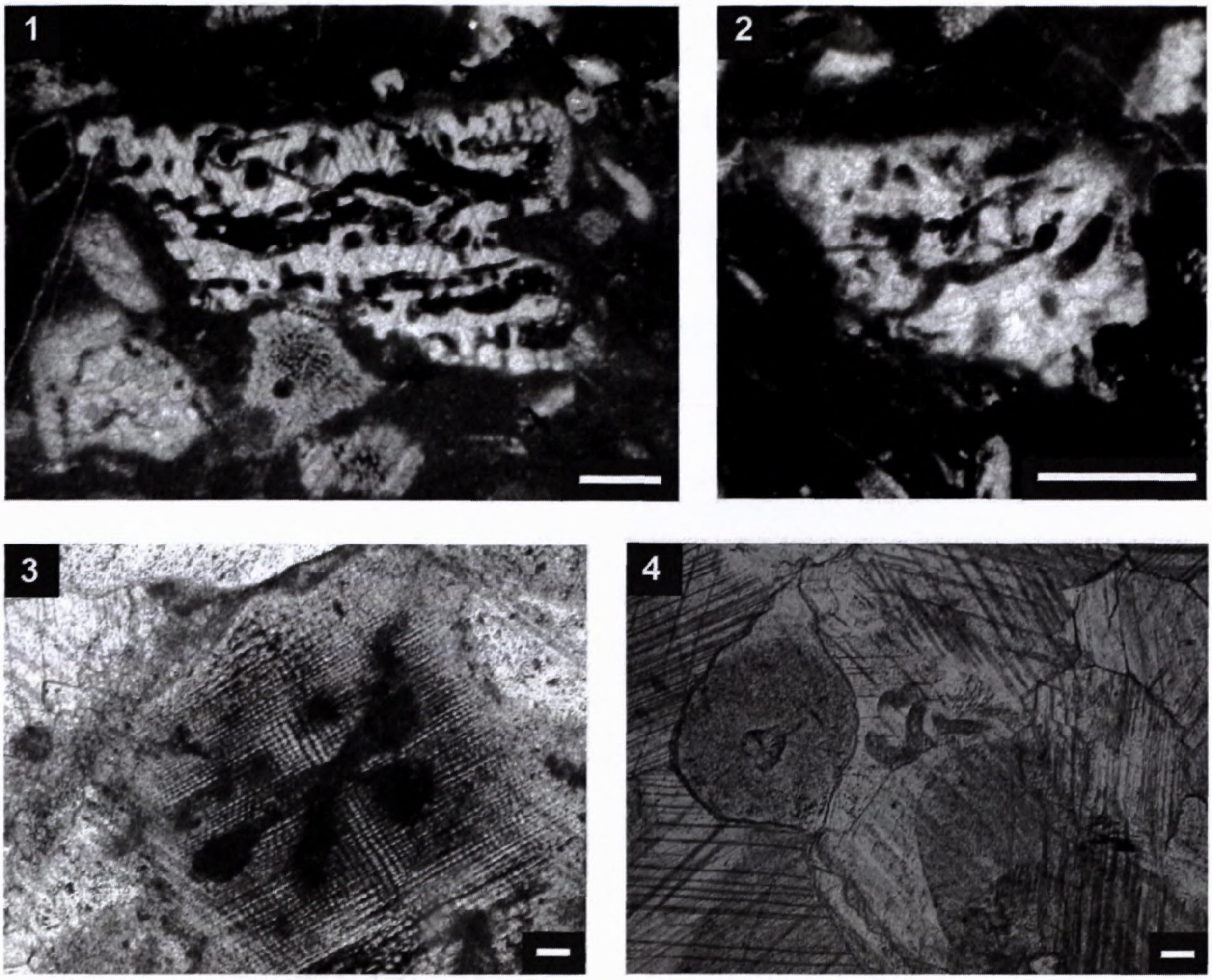

Plate V.

Figs. 1 and 2. Microendoliths in the crinoidal plate filled by Fe-oxides. Toarcian limestone, Krížna nappe, Solisko near Donovaly, Nízke Tatry Mts. Scale bar = 20 μm.

Fig. 3. Stellate boring from the siphonate green alga in a crinoidal plate. Middle Jurassic limestone, Czorsztyn Succession, quarry Krasin near Dolná Súča. Scale bar = 100 μm.

Fig. 4. Microendoliths in the crinoidal limestone. The boring continued in the diagenetic stage; the tunnels penetrated also in the syntaxial rim of the plate. Middle Jurassic limestone. Vysoké Tatry Succession, Javorová valley, Vysoké Tatry Mts. Scale bar = 100 μm.

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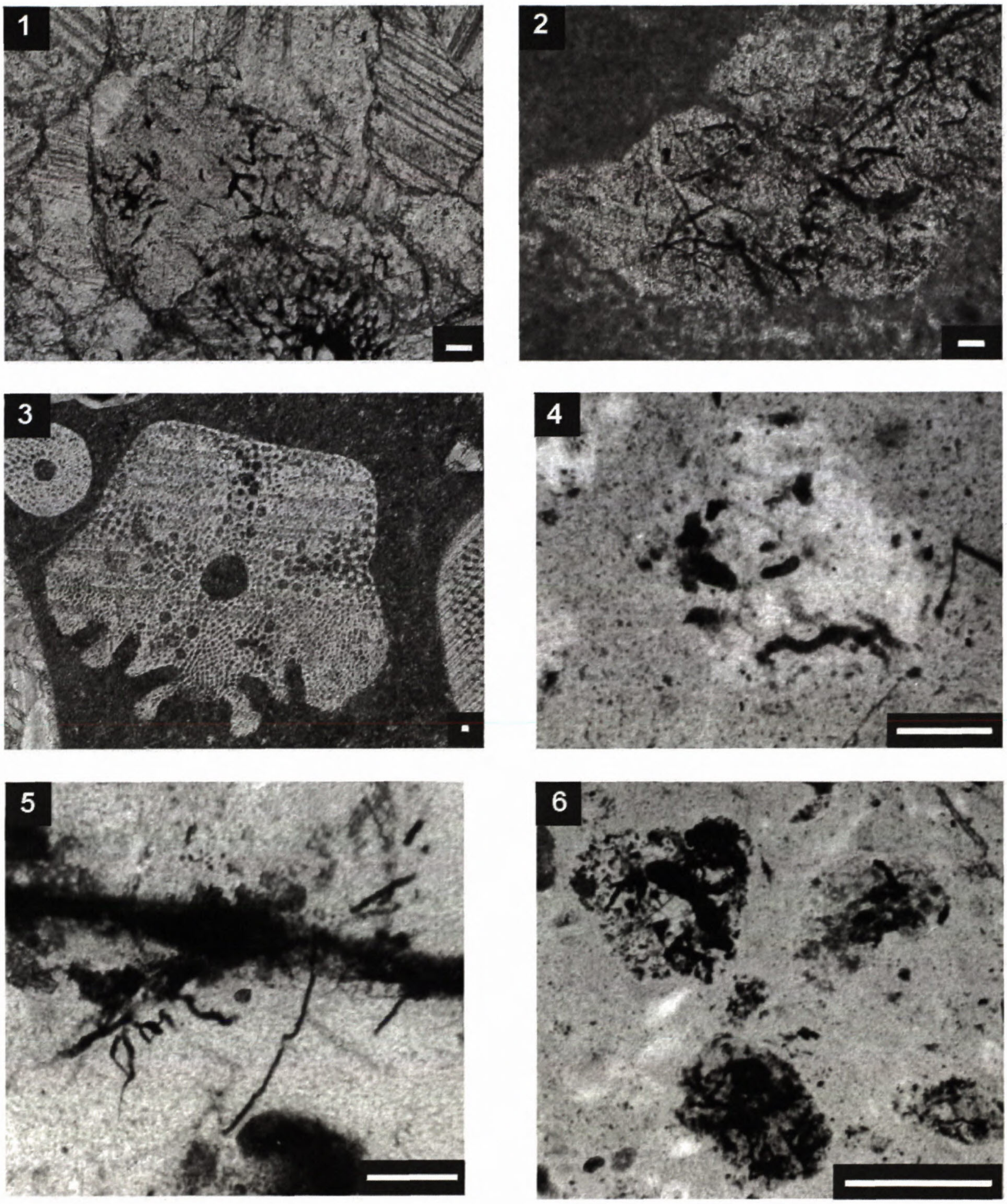

Plate VI.

Fig. 1. Reticular aggregate of microborings in the crinoidal ossicle. Crinoidal limestone, Middle Jurassic, Choč nappe. Quarry Kolíňany, Tríbeč Mts. Scale bar = 100 µm.

Fig. 2. Partly stellate microborings in the crinoidal ossicle. Bathonian limestone, Kostelec Succession of the Pieniny Klippen Belt, Kostelec by Považská Bystrica. Scale bar = 100 µm.

Fig. 3. Two types of microendoliths in a pentagonal columnalium. Liassic limestone, Krížna nappe, Donovaly, Veľká Fatra Mts. Scale bar = 100 µm.

Fig. 4. Undulated tunnels probably in an echinoderm ossicle within the chert. Berriasian limestone of Kysuca (Horná Lysá) Succession, Vršatec, Horná Lysá. Scale bar = 20 µm.

Fig. 5. Undulated corridor in the chert nodule. Turbiditic intercalation in the Berriasian limestone. Vršatec, Horná Lysá. Scale bar = 20 µm.

Fig. 6. Microborings in the crinoidal ossicle and lithoclasts in a chert nodule. Vršatec, the same locality as Figs. 4 and 5. Scale bar = 100 µm.

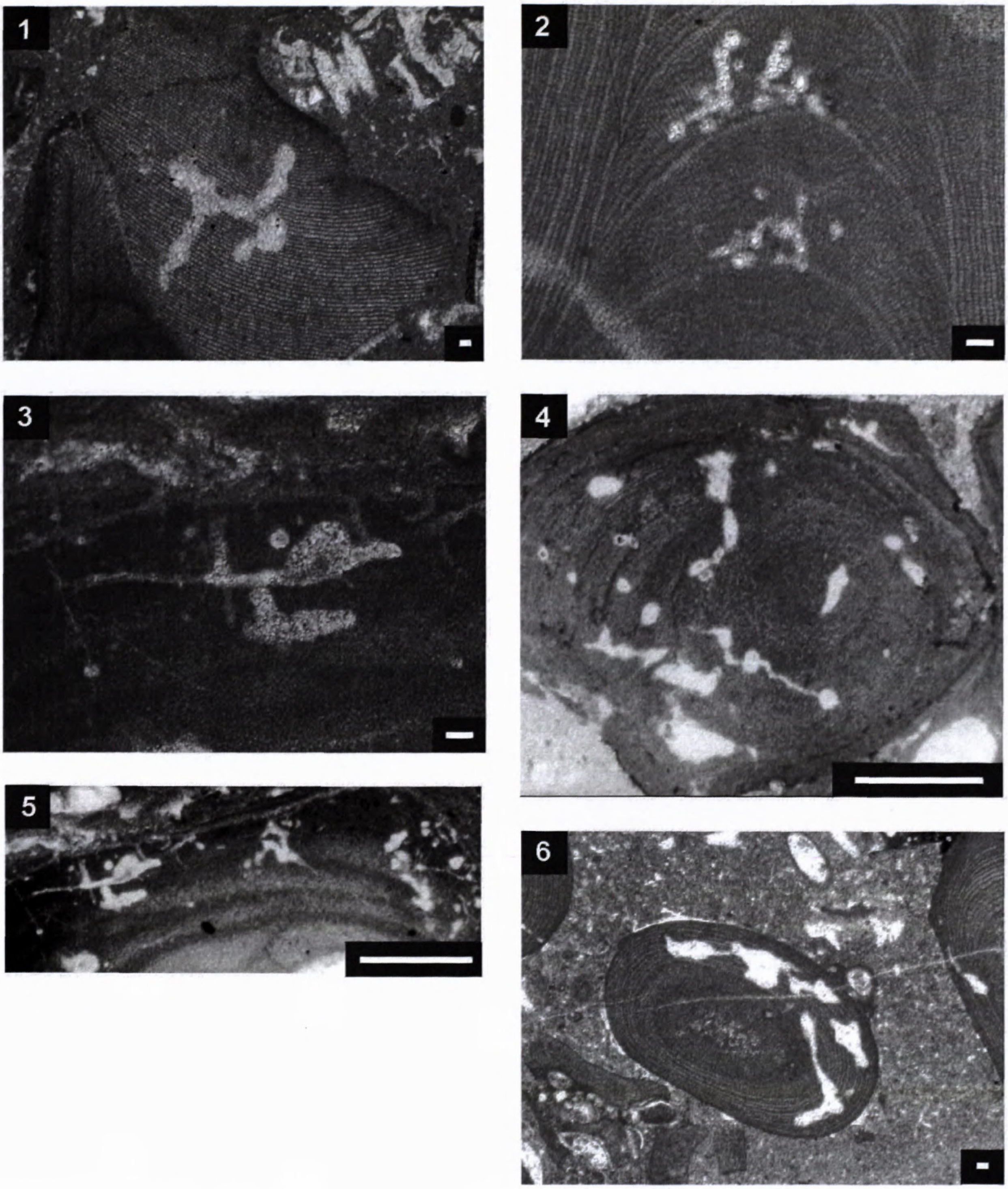

Plate VII.

Fig. 1. Club-shape branched microborings in a coralline alga. Badenian limestone, Rohožník, the margin of Vienna Basin.
Fig. 2. Aggregate of tunnels in the coralline alga. Kambühel limestone, Paleocene. Svätá Helena near Považská Bystrica.
Fig. 3. Boring organism in the coralline alga. Badenian limestone, Strelnica near Štúrovo.
Fig. 4. Borings in a coralline alga. Badenian biohermal limestone, Rohožník, the margin of Vienna Basin.
Fig. 5. Traces of boring organisms with fastigate endings in a coralline alga. Badenian limestone, Strelnica near Štúrovo, Danube Basin.
Fig. 6. Borings in the coralline alga. Kambühel limestone, Paleocene. Makovec near Považská Bystrica.
Scale bars = 100 μm.

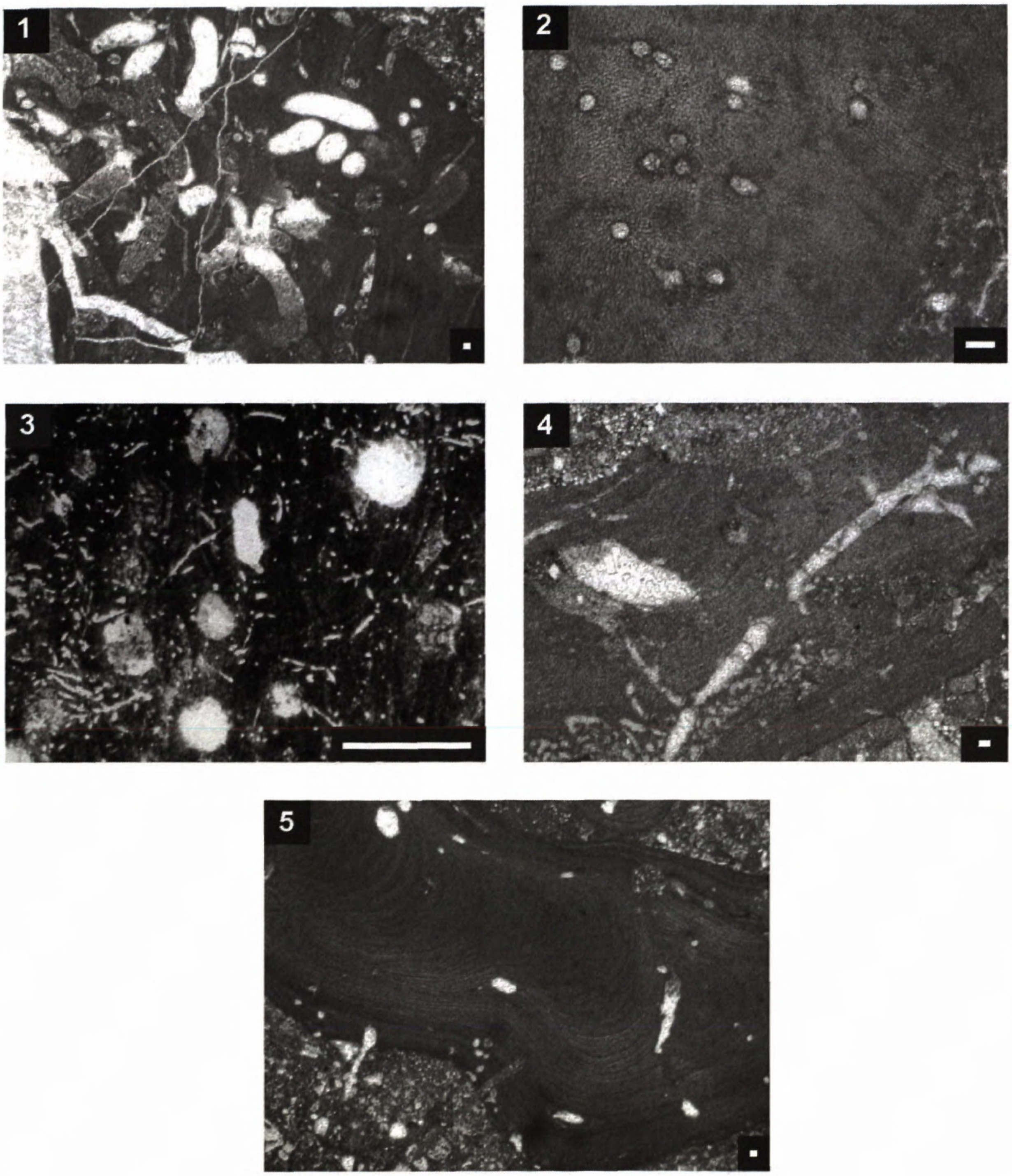

Plate VIII.

Fig. 1. Thicker corridors partly filled by micrite in a coralline alga. Kambühel limestone, Paleocene, Makovec near Považská Bystrica.

Fig. 2. Circular borings in the coralline alga. Kambühel limestone, Paleocene. Cinkov hill, Brezovské Karpaty Mts.

Fig. 3. Two types of borings in a coralline alga. Badenian limestone. Modrý Majer near Štúrovo, Danube Basin.

Fig. 4. Corridor with the sickle-like partitions in the coralline algae. Paleogene limestone. Ground elevation 316, Brezovské Karpaty Mts.

Fig. 5. Perforation from the lithified surrounding mass into the coralline alga. Kambühel limestone, Paleocene. Makovec near Považská Bystrica.

Scale bars = 100 μm.

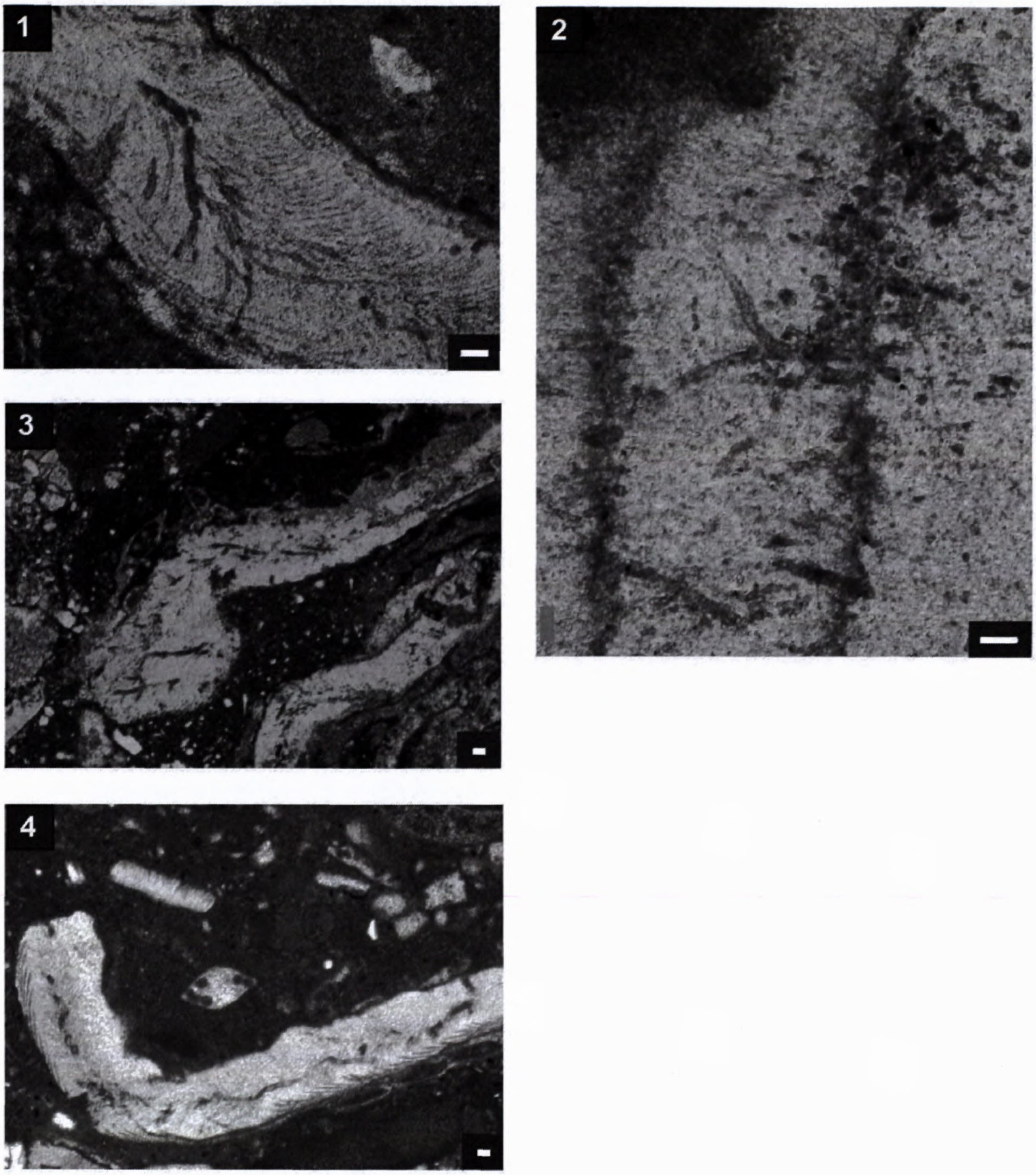

Plate IX.

Fig. 1. Corridors with dichothom fan-like branching with internal articulation in the alga *Ethelia alba*. Paleocene limestone. Saddle over the village Zázrivá.

Fig. 2. Dichothom branching in the alga *Ethelia alba*. Paleocene limestone. Settlement U Černých, Brezovské Karpaty Mts.

Fig. 3. Subparallel microborings in *Ethelia alba*. Santonian limestone. Zemianska Dedina, Orava.

Fig. 4. Long tunnel bored in the axis of the thallus *Ethelia alba*. Paleocene limestone. Brezová pod Bradlom.

Scale bars = 100 μm.

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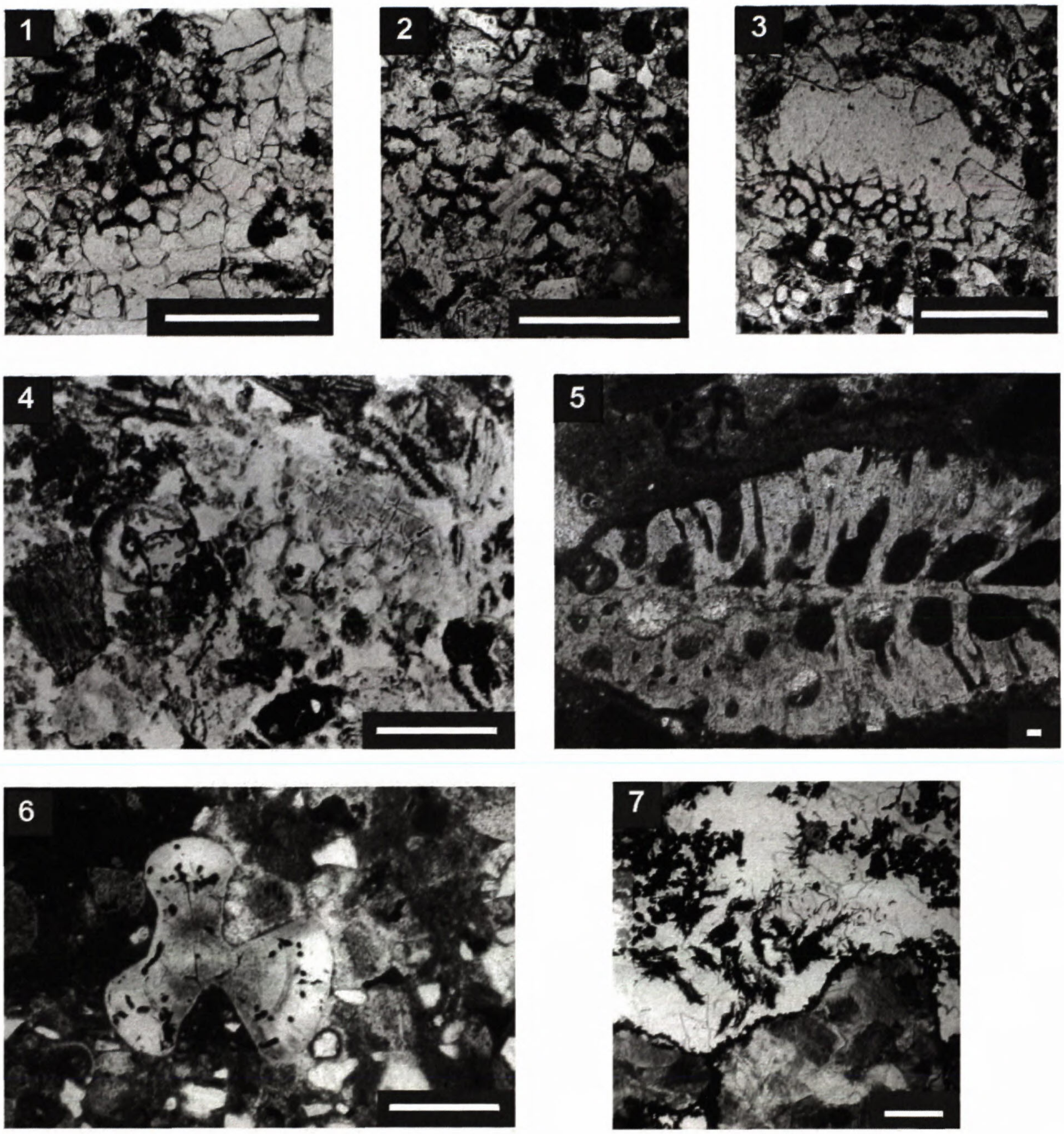

Plate X

Figs. 1.–3. Microboring forming a net with pentagonal loops, probably *Dictyoporus* Mägdefrau in a bioclast of uncertain appurtenance. Sandy *Orbitolina* – bearing Cenomanian limestone. Pebble from the Proč conglomerate with exotic rocks. Proč, Eastern Slovakia.

Fig. 4. Tiny net-like microborings in a bioclast of uncertain appurtenance. Distal turbidite in the Oxfordian radiolarites, Pieniny Succession of the Klippen Belt. Trstená bowling-alley.

Fig. 5. Two types of tunnels bored in bryozoan. Paleocene limestone, Bradový stream, Brezovské Karpaty Mts.

Fig. 6. Borings in the belemnite rostrum. Callovian–Oxfordian limestone, Czorsztyn Succession quarry Krasin near Dolná Súča.

Fig. 7. Tiny tunnels of boring algae in the newly-formed calcite cement within Mn-hardground (dark aggregates). Jurassic limestone, Choč nappe. Quarry between Belušské Slatiny and Mojtín, Strážovské vrchy Mts.

Scale bars = 100 μm.

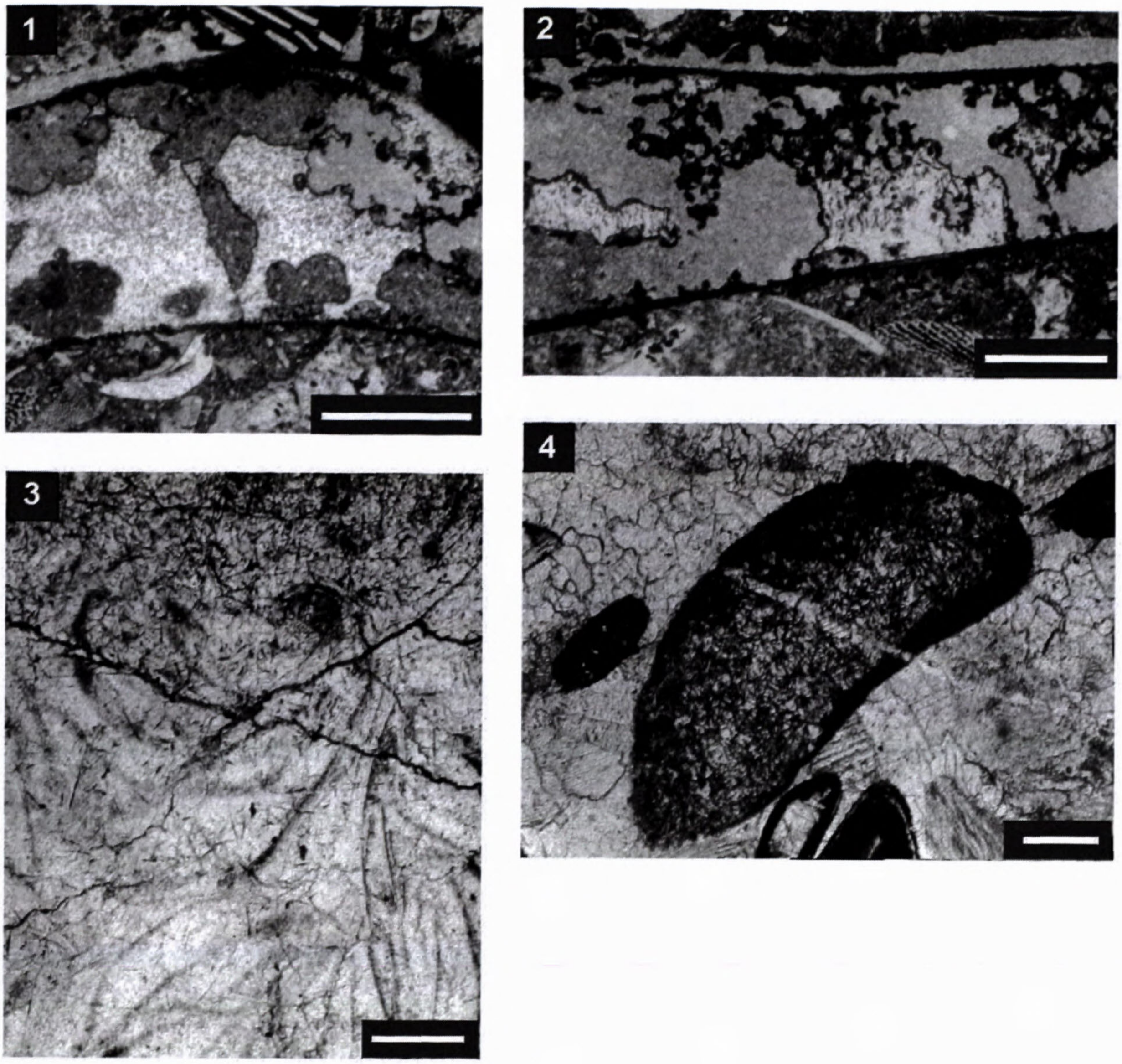

Plate XI

Figs. 1. and 2. Spot-like dissolution of the aragonite shell of an ammonite. The dissolution proceeded selectively according to the accretionary zones of the shell. The voids were formed and filled in three stages. The oldest voids were filled by sparite (clear). Further spaces were filled by dark micrite and the youngest voids of dissolution by clear micrite. In the sparitic voids abundant tiny microborings from the fungi are visible. It is an evidence that the boring activity continued until the diagenetic stage. The shell margins are impregnated by Fe–hydroxides. Upper Lotharingian limestone, Choč nappe. Holý hill near Chtelnica, Čachtické Karpaty Mts. Scale bar = 100 μm.

Fig. 3. Microborings in the terrestric conditions. The surface of Wetterstein limestone covered by lichens. Tiny tunnels belong to the boring fungi. Scale bar = 100 μm.

Fig. 4. Bioclast with a dense cluster of straight tunnels, perhaps redeposited from the continental environment. Lower Liassic biosparitic limestone, Manín Succession. Trenčianske Teplice. Scale bar = 20 μm.