Some notes concerning mineralized hardgrounds (Jurassic and Cretaceous, Western Carpathians). Were all hardgrounds always hard from the beginning?

MILAN MIŠÍK & ROMAN AUBRECHT

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina - G, SK-842 15 Bratislava, Slovakia. E-mail: aubrecht@nic.fns.uniba.sk

Abstract. The paper summarizes rich material of Jurassic and Cretaceous mineralized hardgrounds and oncoids, collected during many years of research. The material comes from all principle West Carpathian units with Jurassic and Cretaceous limestone complexes, in which hardgrounds are developed, e. g. Czorsztyn Unit of the Pieniny Klippen Belt, Tatric, Fatric (Krížna Nappe) and Silicic superunits. The studies of the West Carpathian hardgrounds show some common features that are dealt in detail.

Most of the studied hardgrounds can be divided into two parts: the depositional part, represented by hardground crust and the impregnation part that originated by replacement of underlying limestone. The hardground crusts are commonly represented by mineralized stromatolites, either planar, columnal or sphaeroidal (oncoids). The bacterial colonies that grew through the overlying sediment formed characteristic *Frutexites* aggregates.

Mineralization of the hardgrounds is represented by ferroan and manganese oxides and hydroxides, Fe-chlorite or phosphatic minerals (or various combinations of all). Migration of these minerals is documented not only in the impregnation part of the hardgrounds, but local redeposition of these minerals (especially manganese) into much younger (Tertiary) sediments was documented, too.

Ptygmatitically folded calcite veinlets, that occur in some hardground crusts (depositional parts), seemingly originated by a plastic deformation. More probable explanation is that they represent dehydratation features. Other dehydratation features, e. g. dehydratation shrinkage pores and cracks, are also present.

The mineralized stromatolites (especially oncoids) are rich in encrusting foraminifers, which completely lack in the surrounding sediments. There are also other organisms occurring in the hardground crusts, e. g. sessile bivalves, gastropods etc. In some hardgrounds, serpulid microreefs occur, too. Peculiar is the occurrence of problematic nannofossils *Schizosphaerella*, mostly in Toarcian hardgrounds. Their lack in the surrounding limestones may be explained by merging of their tests with the limestone due to diagenesis. Many studied hardground crusts show extensive boring activity of bivalves, fungi, sponges or algae.

The studied mineralized hardgrounds show rapid diagenetic processes, e. g. rapid aragonite leaching, early precipitation of calcite orthosparitic cement in voids and molds (frequently documented by micro-borings). Another common feature is recrystallization under the influence of migrating Fe-colloids that caused replacement of parts of the stromatolites by newly formed pseudosparitic mosaic.

Key words: Jurassic, Cretaceous, Western Carpathians, hardgrounds, mineralized stromatolites, diagenesis, Schizosphaerella, Frutexites, calcite veinlets, recrystallization.

Introduction

Fine-grained calcareous sediment undergoes relatively rapid lithification, which is evidenced by common lack of compaction features, for instance deformation of allochems and fossils in limestones. This rapid lithification causes that even small interruptions of deposition lead to forming of hardgrounds. Studying thin-sections one commonly meets such purely calcitic micro-hardgrounds that display a minimum erosional removal and sharp contact with overlying layer, being commonly represented by similar limestone, just with slightly different texture. Short time non-deposition caused that such surface neither was pigmented by Fe and Mn compounds, nor coated by their crusts or inhabited by sessile and boring organisms. On the other hand, mineralized hardgrounds reflect events of more important meaning. They are mostly related to sea-level rise or sea-level highstand, resulting in considerable drop of terrigenous influx and cessation of sedimentation. Such hardground occurrences are related to condensed sedimentation commonly represented for instance by Ammonitico Rosso facies. Therefore, such events were primary tied to certain stratigraphic horizons that are mutually well correlable. Other type of hardgrounds may rise as a response to change in bottom current regime by influx of cooler waters that are rich in CO_2 and leach carbonate matter. The change of currents may be caused by a different process than in the first instance, i.e. by sea-level drop and shallowing. The most frequently, however, the current regime changes under influence of local factors as changes in sea-bottom configuration due to synsedimentary tectonics, extensional

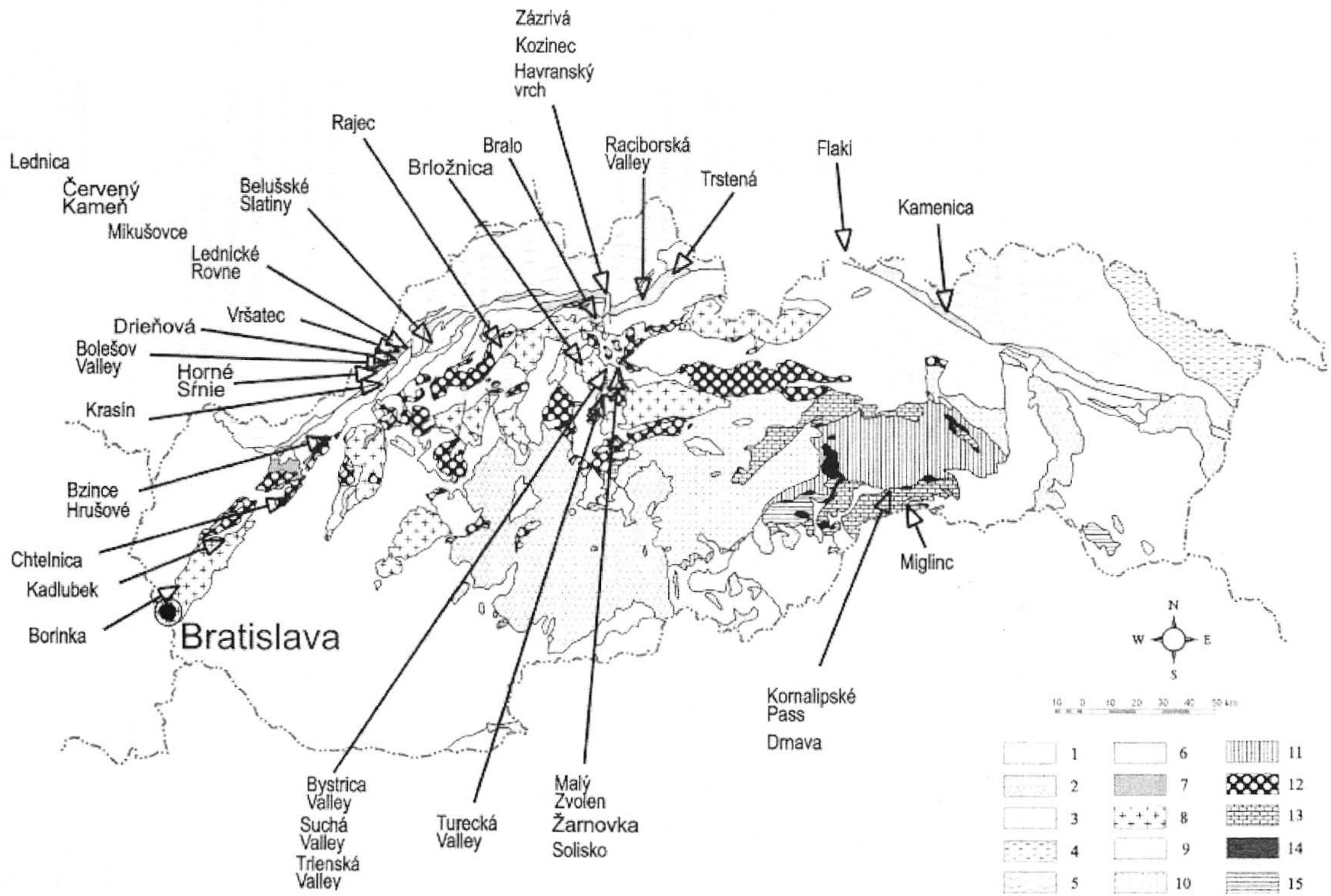


Fig. 1. Position of the sampled localities within the frames of the West Carpathian geological structures. Legend: 1. Fill of the Neogene basins, 2. Neogene volcanics, 3. Paleogene basins, 4. Outer Flysch Belt units, 5. Inner Flysch Belt units, 6. Pieniny Klippen Belt - Oravic units, 7. Senonian of the Central and Inner Western Carpathians, 8. Tatric units, 9. Fatric units, 10. Veporic Unit, 11. Gemeric Unit, 12. Hronic units, 13. Silicic units s. l., 14. Meliaticum, 15. Turnaicum, Zemplinicum and other units of the Inner Western Carpathians.

fracturing and sinking of some bottom parts along faults. In such cases there is no relation to the global eustatic curve and distant correlation of hardground horizons is impossible.

The term hardground involves only lithification of originally soft sediment on the sea-bottom or slightly below the sediment/water boundary, whereas primarily hard, rocky parts of the bottom are termed hardrock (e. g. toes of shore cliffs, drowned reefs and lithified platforms etc.). Similarly, neptunian dykes have their walls of hard, previously lithified limestones. Although they are commonly coated by cryptic stromatolites of various composition and their filling frequently contains detritus of such coatings, these will not be included to this paper. This paper is only focused on mineralized hardgrounds. Generally condensed sedimentation is expressed not only by mineralized stromatolitic crusts but also their detritus and mineralized oncoids. The mineralization use to be manganese, ferroan, Fe-chloritic or phosphatic. These four mineral types are commonly closely related and sometimes occur even in one sample. Therefore, we will not treat the mineralized hardgrounds separately by their mineralogical and chemical composition.

Stratigraphically and paleogeographically, numerous examples of hardgrounds are known from the Jurassic and Lower Cretaceous sediments deposited on so called pelagic swells (García-Hernandéz et al., 1988). In the Western Carpathians they are mostly known from the Czorsztyn Swell of the Pieniny Klippen Belt (Mišík, 1994).

Our studies of West Carpathian hardgrounds (for the location see Fig. 1) show some common features that are dealt in detail in the following parts and will be documented by microphotos. The features are as follows: metasomatic parts of mineralized hardgrounds, stromatolite crusts passing to *Frutexites* textures, Fe, Mn, P and chloritic oncoids (with considerable amount of micritic calcite), boring organisms (algae, fungi, bivalves, polychaets), special nannoplankton, mostly *Schizosphaerella punctulata* fossils in hardgrounds, mainly encrusting foraminifers, peculiar structures in crusts (alveolar, fenestral, spongiform), deformed veinlets, very early orthosparite and frequent recrystallization phenomena (pseudosparite). The next chapters are dedicated to description of these phenomena, their occurrences and interpretation.

Problem of ptygmatitic calcite veinlets in some hardground crusts

Syndepositional hard consistence of mineralized hardground crusts is evidenced by boring organisms, attached sessile organisms preferring hard substrates and angular fragments of reworked hardground crusts. However, extremely (ptygmatitically) folded calcite veinlets were found in some crusts, e.g. from the Albian hardground at Vršatec–22 locality (Czorsztyn Unit, Pieniny Klippen Belt, Tab. 1, Fig. 1-2) and from a chlorite oncoid of Oxfordian age from Bralo locality in Zázrivá Valley (Tatric Unit, Malá Fatra Mts., Tab. 1, Fig. 3). At first sight, these veinlets remind plastically deformed structures that would infer plastic or semi-plastic stage during formation of the hardground crusts. In several instances, breakage of the ptygmatitic veinlets was observed, e.g. in the Toarcian hardground crust at Kadlubek locality (Malé Karpaty Mts., Tab. 1, Fig. 4), Middle Jurassic crust at Červený Kameň near Pruské (Tab. 1, Fig. 5) and Albian crust at Horné Sŕnie (Tab. 1, Fig. 6). Possibility of plastic deformation of some hardground crusts is also supported by synsedimentary bending of the crust found near Hrušové (Rojkovič et al., 2003, Fig. 4.3). The plastic deformations and breakage of the veinlets might be induced by local seizmic events. Temporary plastic stage may be caused by rapid precipitation of several milimetres of the future hardground crust, most probably from local hydrotherms. Such origin was also inferred for similar deformations - folding and breakage of veinlets in radiolarites at Trstená-Kolkáreň locality (Mišík et al., 1991, Tab. 4, Fig. 1), where this assumption was supported by presence of barite. However, no such evidence was found in the studied hardground crusts.

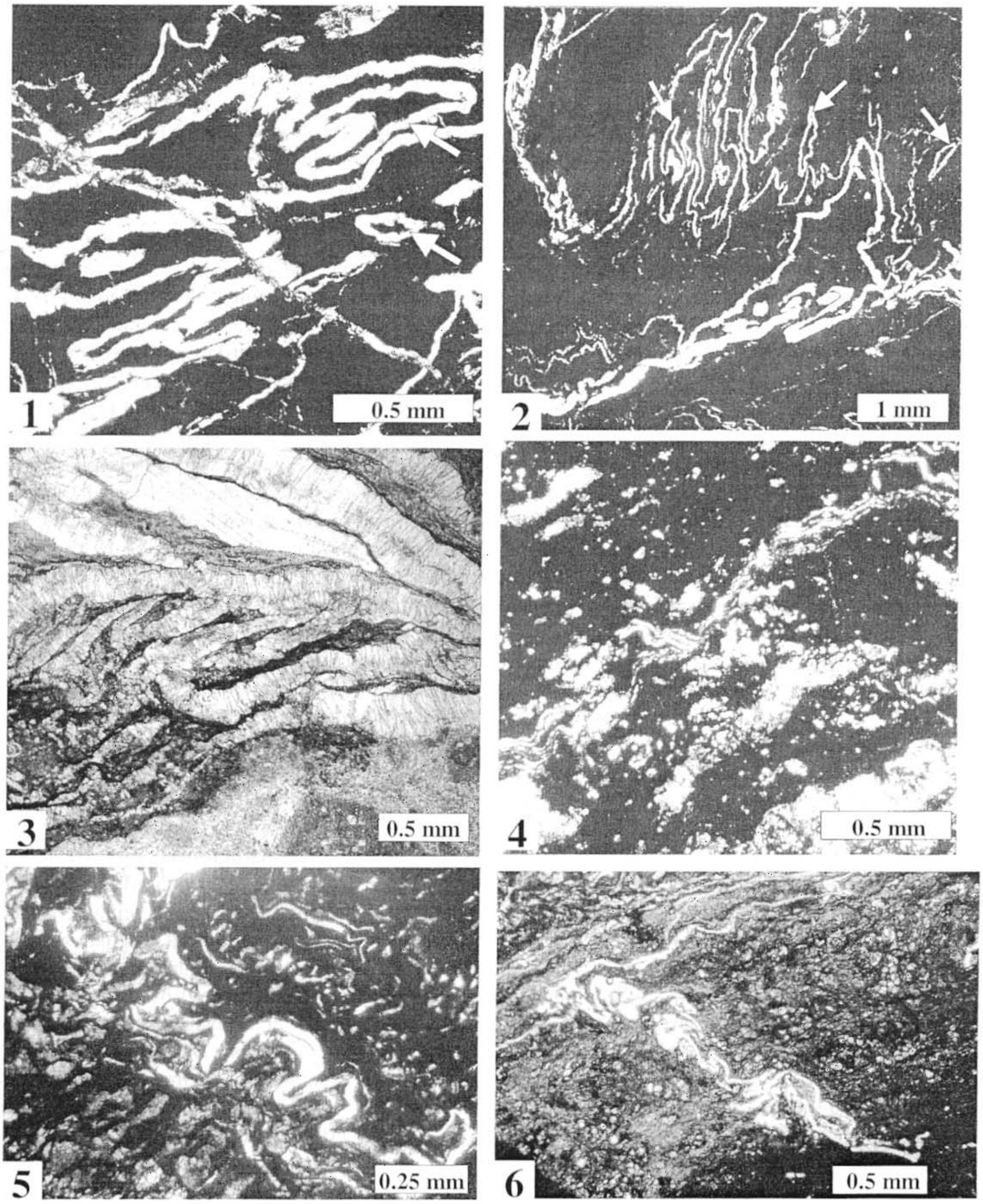
Other possible explanations of the veinlet deformation may be that the crusts were cut tangentially and slight irregularities of the surface would appear in thin sections like heavily deformed veinlets. However, this assumption is contradicted by fibrous calcite filling of some veinlets (Tab. 1, Fig. 4). The fibres are oriented perpendicular to the veinlet walls and parallel to the thin section. If the veinlets would be cut tangentially, the fibres would be oriented perpendicular to the thin section, having appearance of equant microsparite.

The most probable explanation of most of the cases is contraction of the hardground crusts by dessication. This is evidenced by relatively uniform thickness of the veinlets and by the fact that the veinlets in some instances form circular, oval or other, irregular but closed bodies (Tab. 1, Fig. 1-2). Original higher portion of water in the hardgrounds is also inferred by network of anastomosing pores, fenestral and alveolar textures and dessication cracks (Tab. 2, Fig. 1-4). Dehydration and contraction can occur still in submarine environment that was documented by several works of Donovan & Foster (1972), Plummer & Gostin (1981) and Pratt (1998). Several manganese minerals occurring in the hardground crusts, such as romančchite - $(Ba,H_2O)_2(Mn^{+4},Mn^{+3})_5O_{10}$, todorokite - $(Mn^{+2},Ca,Mg)Mn^{+4}{}_3O_7.H_2O$ or rancieite - $(Ca,Mn^{+2})Mn^{+4}{}_4O_9.3(H_2O)$, contain substantial amount of water. Its expulsion by mineralogical changes can also lead to changes in volume that may probably result in origination of voids.

Metasomatic (impregnation) and depositional parts of hardgrounds

In most cases, depositional and metasomatic parts can be distinguished in the mineralized hardgrounds (Tab. 2, Fig. 5-6). **Depositional part** originates by deposition on the calcareous bottom sediment in form of pelagic stromatolites with fine, regular lamination that originated by assistance of bacteria, sessile organisms. The deposition is sometimes accompanied by fine-grained breccias and oncoids. **Metasomatic (impregnation) part** of hard-

Slovak Geol. Mag., 10, 3 (2004), 183 – 202



Tab. 1.

Fig. 1. Ptygmatitic calcite veinlets in manganolitic hardground crust. The phenomenon most likely points to contraction of the hardground crusts by dessication, as also evidenced by some veinlets closed in deformed circles and ovals (arrows). Kimmeridgian-Lower Tithonian hardground of the Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.

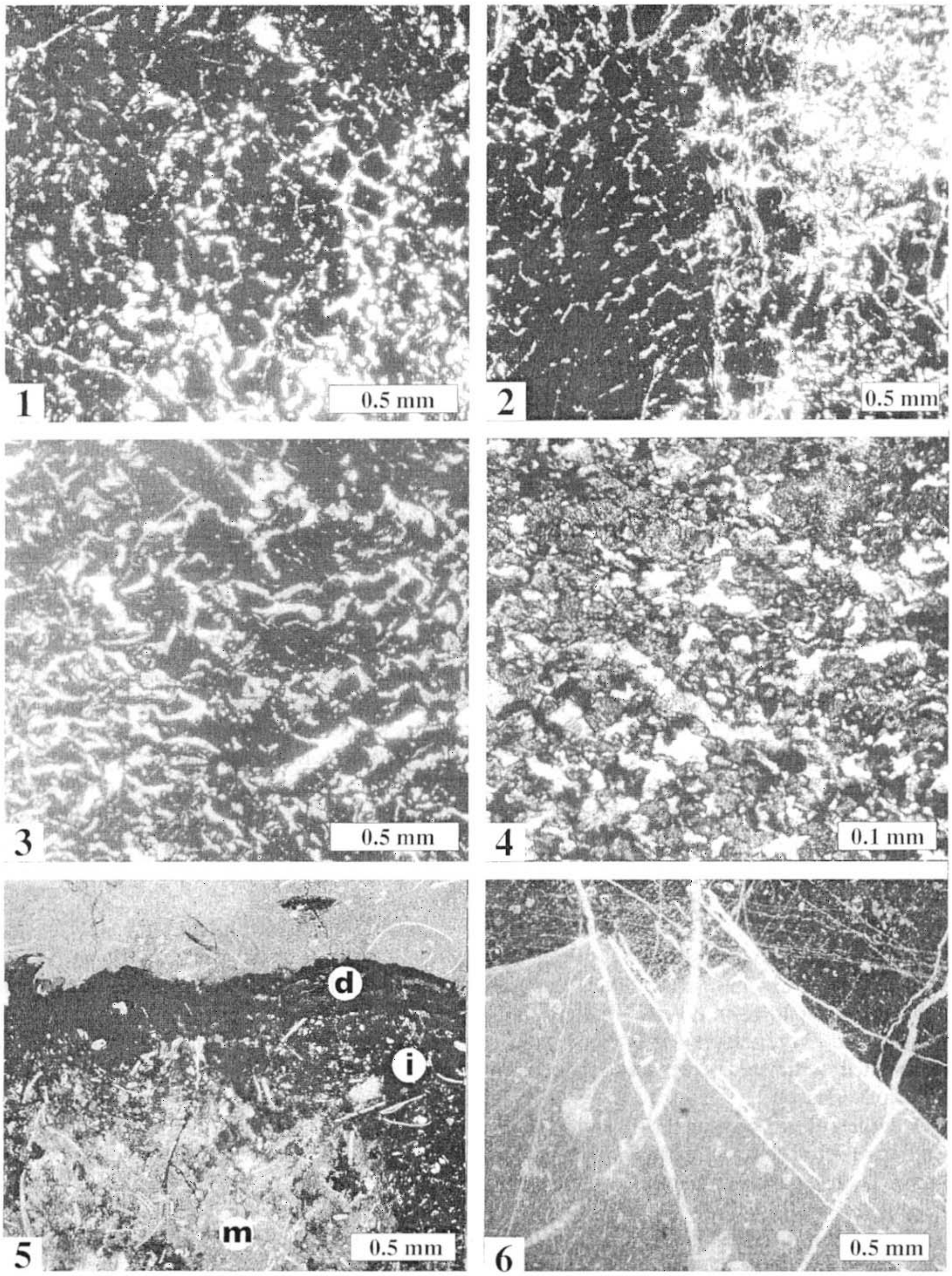
Fig. 2. The same in a different thin-section.

Fig. 3. Ptygmatitic veinlets in chloritic hardground crust. Dehydratation and shrinkage was accompanied by growing of fibrous calcite and, successively, by compactional breakage of newly formed veinlets. Oxfordian hardground, Tatric Superunit (Malá Fatra Unit), Malá Fatra Mts.; loc. Bralo - Zázrivá Valley.

Fig. 4. Thin, subparallel calcite veinlets in ferroan hardground crust. The veinlets either underwent synsedimentary deformation, or they represent dewatering features. Toarcian hardground, Tatric Superunit (Kadlubek Unit), Malé Karpaty Mts.; loc. Egreš Section near a gamekeeper's cottage.

Fig. 5. Strongly undulated calcite veinlet in ferroan hardground crust. Callovian-Oxfordian hardground, Czorsztyn Succession, Pieniny Klippen Belt; Sivá skala Klippe near Červený Kameň (Váh River Valley).

Fig. 6. Undulated calcite veinlets that underwent compactional breakage. Albian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Horné Sŕnie - the topmost cement quarry.



Tab. 2.
Fig. 1. Reticular (network) texture originated by dehydratation and syneretic cracking of Mn colloids in the hardground crust. Kimmeridgian-Lower Tithonian hardground, Czorsztyn Unit, Pieniny Klippen Belt, loc. Vršatec 47.
Fig. 2. Reticular texture in an Mn crust. Loc. - as previous.
Fig. 3. Anastomosing structure of syneretic cracks in a Mn hardground. Like in the previous figures, the cracks are filled with calcite. Note some similarity with ptygmatitic calcite veinlets from the same locality (Tab. I, Fig. 1-2). Loc. - as previous.
Fig. 4. Fenestral structures in manganolite: They probably represent structures originated by dehydratations shrinkage, similar as in intertidal carbonate sediments. Callovian-Oxfordian hardground crust, Czorsztyn Unit, Pieniny Klippen Belt; loc. Mikušovce-354.
Fig. 5. Example of hardground with preserved both, the depositional and impregnation parts. The black layer, free of skeletal remnants, represents the depositional part (d); the black part with white, unreplaced skeletal remnants (micritic matrix replaced by haematite) is the impregnation part of the hardground (i). The impregnation gradually passes to unaffected Bathonian-Callovian micritic limestone with „filamentous" microfacies (m). Czorsztyn Succession, Pieniny Klippen Belt; loc. Bolešov Valley.
Fig. 6. Example of hardground with only impregnation part preserved. Haematitic impregnation (replacement) of the underlying limestone has stopped on bivalve shells that represent a natural lower limit of the hardground. Upper Berriasian hardground, Krížna Nappe (Ďurčiná Succession), Malá Fatra Mts.; loc. Rybná Valley near Rajec.

ground is represented by impregnation of the underlying limestone. The impregnation is usually shallow; its depth is irregular. The impregnation is often stopped on obstacles, like veinlets, bivalve shells (Tab. 2, Fig. 6) etc. In this part, traces after boring organisms are usually developed. In some hardgrounds, solely the impregnation part is developed, such as the haematitic impregnation in Upper Berriasian limestone of Rybná Valley ner Rajec (Tab. 2, Fig. 6). In the cases when the borings are missing, such hardground might originate in a certain depth below the sediment/water interface. Such hardgrounds may be subsequently exhumed by erosion and, locally, later complemented by a depositional part.

Mineralized stromatolites

As the mineralized stromatolites usually originate below the photic zone, the terms pelagic stromatolites and oncoids are used for them. Their origin is rather related to bacteria or cyanobacteria than to green algae. Stromatolites in the studied hardgrounds possess various shapes, from almost planar, through slightly undulated to hemisphaeroidal (LLH) and columnal (Tab. 3, Fig. 1-5). Rhythms of lower order can be distinguished within the individual stromatolites. For instance, branching columnal stromatolites follow after hemispheroidal stromatolite (Tab. 3, Fig. 5). In manganese hardgrounds, the most simple, individually separated hummocky (mammilary) stromatolites occur locally. Besides the most common upward growth orientation, opposite downward orientation may occur in voids (endostromatolites); in some voids, two stromatolites growing opposite to each other can be observed in thin sections (e. g. localities Bolešov Valley, Bzince pod Javorinou, Vršatec-47). In some instances, stromatolites grew into voids after leached bivalves or ammonites. Apart from normal, free growing stromatolites, so called *Frutexites* evidently grew within the already deposited sediment. A separate chapter is dedicated to this phenomenon.

During growth there were common changes in mineral composition of stromatolites; for instance, haematitic stromatolite turns to manganese or phosphatic stromatolite during the growth.

Peculiar are radially dissected hemispheroids (loc. Drieňová, Tab. 4, Fig. 4; Vršatec-47, Tab. 4, Fig. 5). Thin channels filled with sparite, oriented normal to the growth lines of stromatolite, may represent traces after erected algal fibres. The radial dissection is more common in oncoids (see the next chapter).

Maximum thickness of stromatolite, 4 cm, has been found at Drieňová Hill locality. Pelagic stromatolites are generally considered to be formed by cyanobacteria; the mineralized stromatolites are evidently formed by ferroan, manganese and other bacteria.

Mineralized oncoids

Detailed description of mineralized oncoids from the Toarcian of the Veľká Fatra Mts. and Upper Jurassic of the Malá Fatra Mts. was provided by Mišík & Šucha (1997). Herein, only some summarized observations are mentioned.

The maximum perimeter of Jurassic Fe-Mn oncoids from some localities are: Brložnica - 2 cm, Skalka-Raciborská Valley - 3 cm, Kozinec - 4 cm, Havranský vrch - 4 cm, Malý Zvolen - 4 cm, Drieňová Hill - 4 cm, Kornalipské Pass - 5 cm, Gader Valley - 5 cm, Bzince - 6 cm, Chtelnica - 6 cm, Bralo-Zázrivá Valley (chlorite oncoids) - 7 cm. Phosphatic and ferroan oncoids found in the Albian of the Czorsztyn Succession (Horné Sŕnie, Jarabina) attained smaller dimensions (Horné Sŕnie-1 - 1 cm, Horné Sŕnie-3 - 2 cm, Brložnica - 2 cm). The most common maximum perimeters are then about 4 cm.

Oncoid cores are formed by carbonate intraclasts, often different from the surrounding limestone (e.g. Bzince, Kornalipské Pass). Frequently, the clasts are corroded. Other cores are sometimes represented by debris of older oncoids (for instance Drieňová Hill), rarely by bioclasts (e.g. belemnite guards - Gader Valley, see Mišík, 1966, Tab. XLIV, Fig. 2). Some oncoids contain two cores (Tab. 4, Fig. 2)

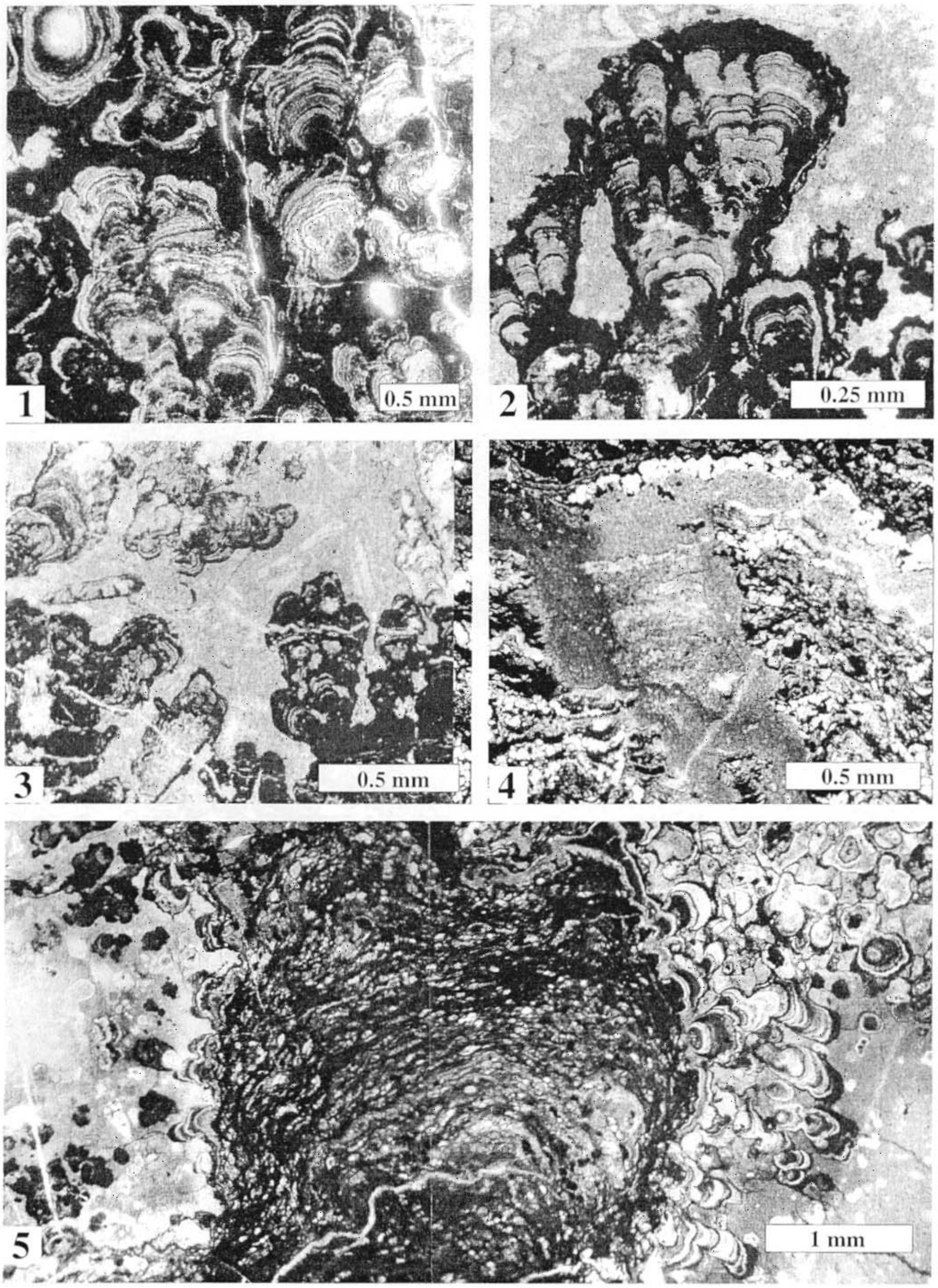
Most common are Fe-Mn oncoids; chloritic oncoids were found only in the Lower Jurassic sediments at the localities Gader Valley, Bystrica Valley, Suchá Valley, Trlenská Valley, Veľká Turecká Valley, Žarnovka, Skalka-Raciborská Valley. Upper Jurassic chlorite oncoids were found at Bralo-Zázrivá Valley. Phosphatic oncoids, usually of smaller dimensions, were found only in Lower Jurassic and Albian sediments (Horné Sŕnie, Brložnica). Like other mineralized stromatolites, some oncoids show changes in mineral composition during their growth (see the previous chapter).

Shape of the oncoids is commonly ovoidal (Tab. 4, Fig. 1) that in some instances points to compactional flattening. The flattening is locally accompanied by forming of dilatational calcite veinlets which remind those originated by dehydratation (Tab. 4, Fig. 4). Fragments of older oncoids in the cores even indicate fracturing of oncoids still in the sedimentary environment. This is also evidenced by neptunian microdykes cutting the oncoids (these occur also in other forms of mineralized stromatolites, Tab. 3, Fig. 4). Oncoids, as well as stromatolites, are sometimes characterized by a peculiar vertical dissection, likely caused by vertically growing algal fibres (Tab. 3, Fig. 3-6).

Migration and relocation of compounds from the Mn-hardgrounds

Manganese, as a highly mobile element, can be redeposited from hardground crusts into younger formations. In the Western Carpathians, manganese redeposites were found in caverns in Kimmeridgian-Lower Tithonian limestones (Mišík & Rojkovič, 2002). The manganese, originally coming from the Middle Jurassic hardgrounds, was redeposited during the Early Cretaceous emergence of the Czorsztyn Swell. The manganese cavern filling was accompanied by clasts of Upper Tithonian limestones and fresh-water algae (Tab. 5, Fig. 4, see also Dragastan & Mišík, 2001).

Migration of the Mn compounds from the Middle Jurassic hardground crusts also occurred during Tertiary emersion, as evidenced by a veinlets filled with Mn minerals, cutting an older cavity with Senonian globotruncanid foraminifers (Horné Sŕnie, Tab. 5, Fig. 1-3). It is noteworthy that also in this case, the manganolitic filling is associated with fresh-water algae (or cyanobacteria). The algae have not been yet described; their fibres have a peculiar triangular cross-section (Tab. 5, Fig. 3).



Tab. 3.

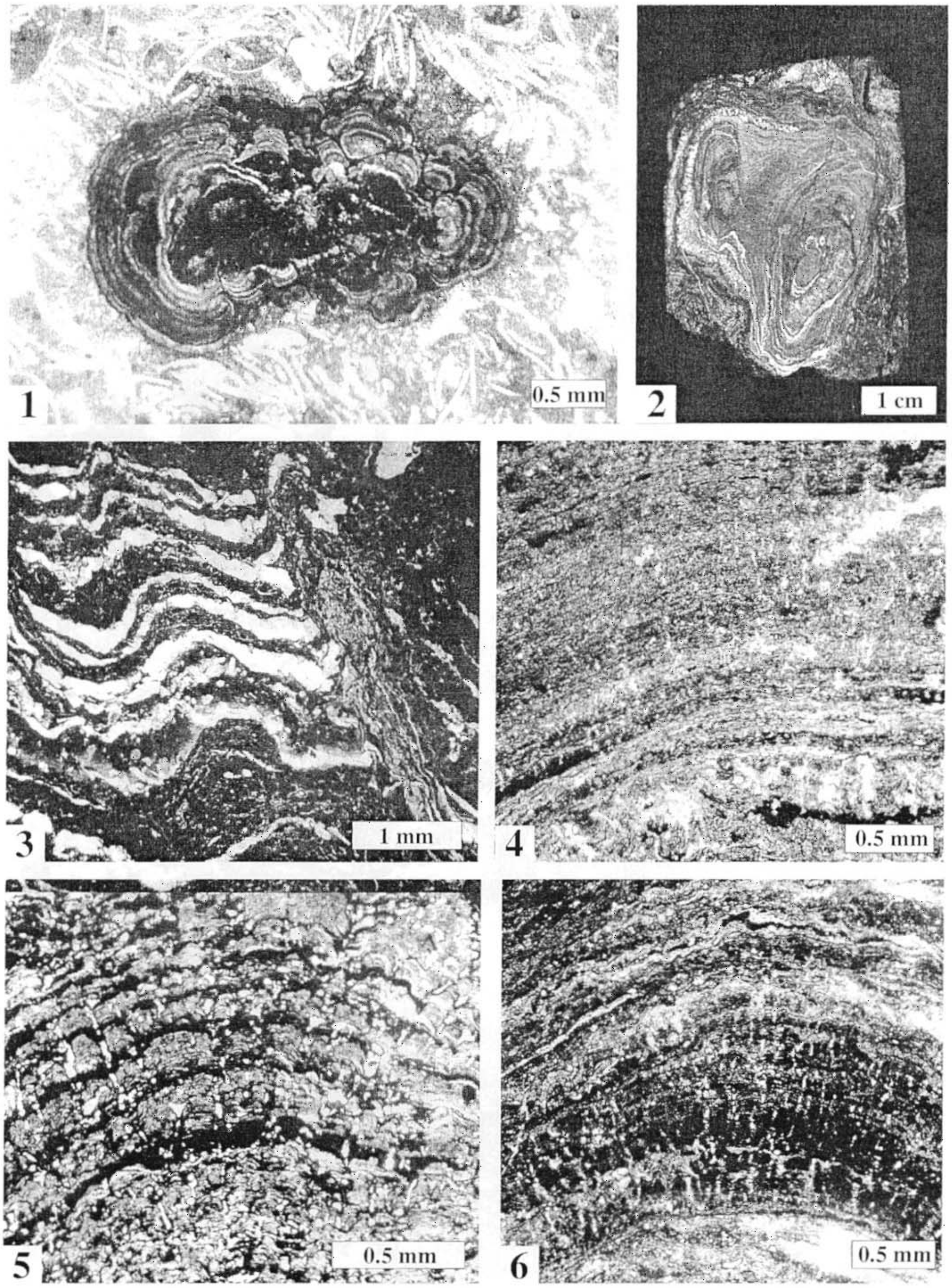
Fig. 1. Phosphatic stromatolites in Albian hardground. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec - Castle Klippe (above the ski lift).

Fig. 2. Manganese stromatolite in Kimmeridgian-Lower Tithonian limestone. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.

Fig. 3. Manganese-calcitic stromatolites in hardground. Loc. - as previous.

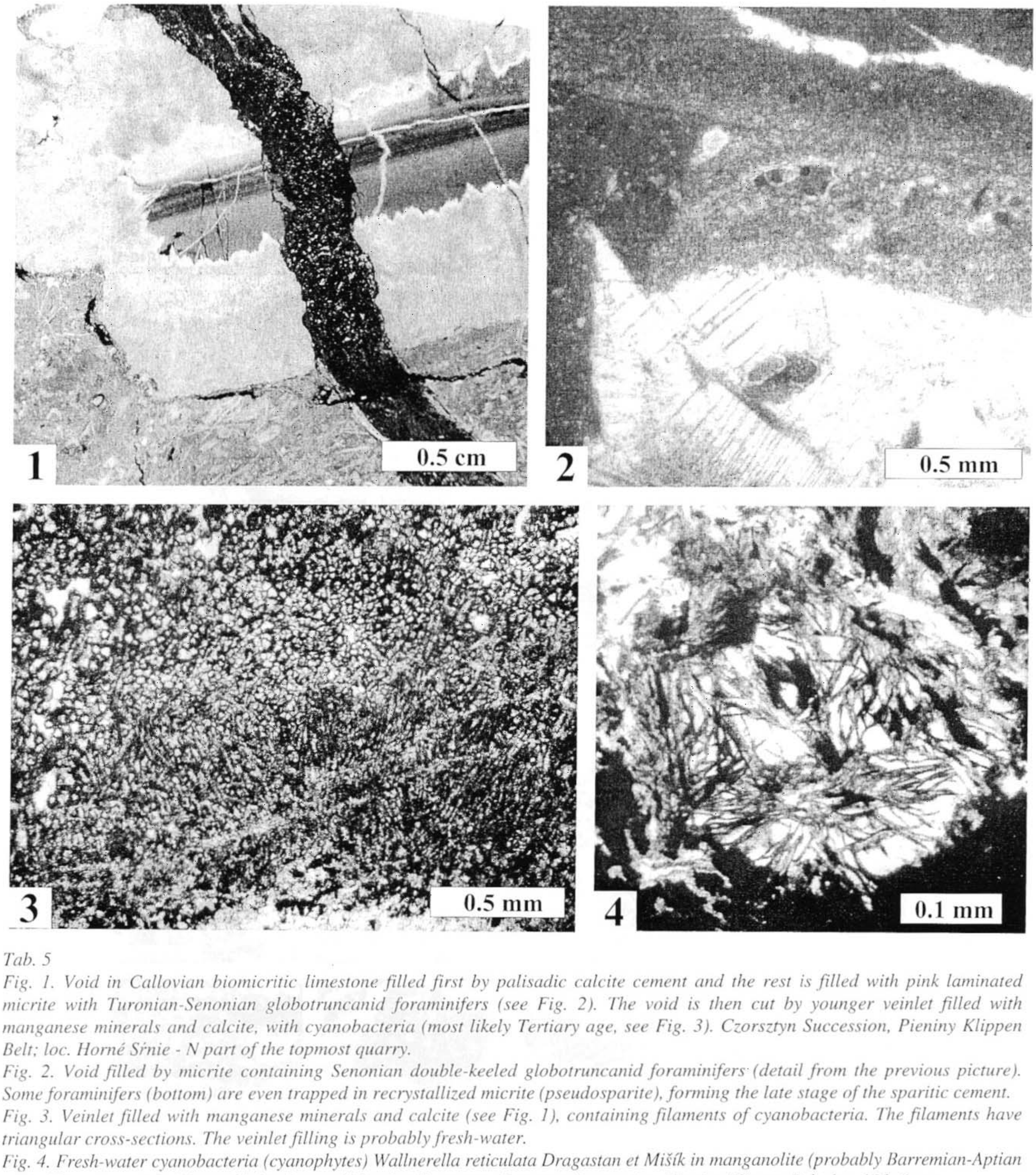
Fig. 4. Neptunian microdyke in stromatolite. Lower Jurassic hardground, Krížna Nappe, Veľká Fatra Mts.; loc. Gader Valley.

Fig. 5. Domatic Fe-stromatolite (detail of a hardground) encrusted by tiny columnal phosphatic stromatolites. The latest generation is represented by Frutexites (left part). Albian hardground in red marly pelagic limestones, Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec - the southernmost coulisse



Tab. 4.

Fig. 1. Fe-oncoid in a limestone with „filamentous" microfacies (juvenile Bositra shells). Bathonian-Callovian of the Czorsztyn Succession, Pieniny Klippen Belt; loc. Červený Kameň near Pruské.
Fig. 2. Manganese oncoid with twin core. Upper Toarcian hardground in nodular limestones, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Bzince pod Javorinou.
Fig. 3. Concentric veinlets formed by pressure dilatation of the distal edges of flattened Fe-oncoid. Toarcian nodular limestones, Orava Succession, Pieniny Klippen Belt; Havranský vrch near Zázrivá.
Fig. 4. Stromatolite penetrated by perpendicular filaments. Bathonian-Callovian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Drieňová near Krivoklát.
Fig. 5. Fe-oncoid penetrated by perpendicular filaments. Kimmeridgian-Lower Tithonian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.
Fig. 6. Fe-oncoid penetrated by perpendicular filaments. Bathonian-Callovian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Drieňová near Krivoklát.



Tab. 5

Fig. 1. Void in Callovian biomicritic limestone filled first by palisadic calcite cement and the rest is filled with pink laminated micrite with Turonian-Senonian globotruncanid foraminifers (see Fig. 2). The void is then cut by younger veinlet filled with manganese minerals and calcite, with cyanobacteria (most likely Tertiary age, see Fig. 3). Czorsztyn Succession, Pieniny Klippen Belt; loc. Horné Sŕnie - N part of the topmost quarry.

Fig. 2. Void filled by micrite containing Senonian double-keeled globotruncanid foraminifers (detail from the previous picture). Some foraminifers (bottom) are even trapped in recrystallized micrite (pseudosparite), forming the late stage of the sparitic cement.

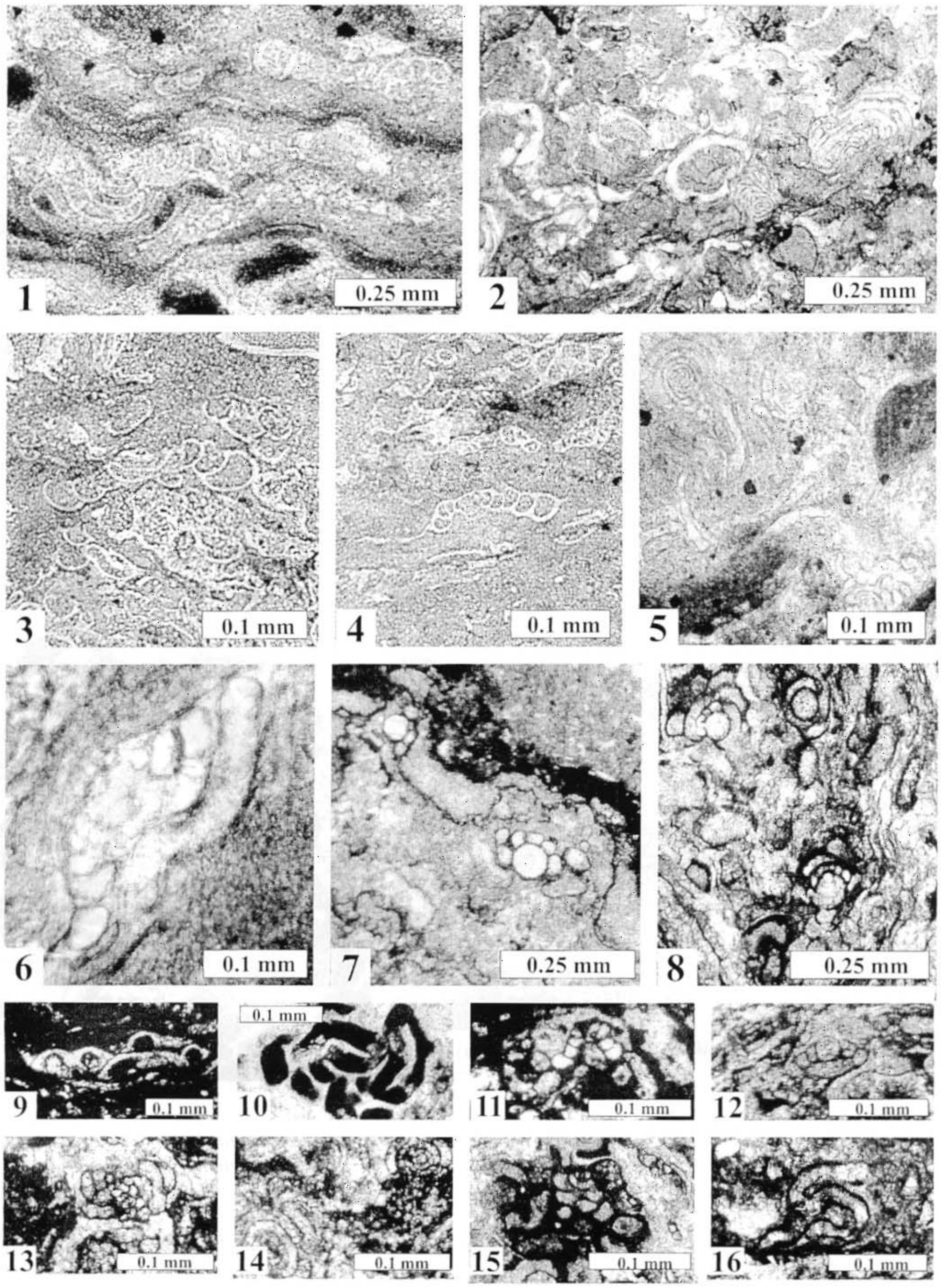
Fig. 3. Veinlet filled with manganese minerals and calcite (see Fig. 1), containing filaments of cyanobacteria. The filaments have triangular cross-sections. The veinlet filling is probably fresh-water.

Fig. 4. Fresh-water cyanobacteria (cyanophytes) Wallnerella reticulata Dragastan et Mišík in manganolite (probably Barremian-Aptian age), filling caverns in Kimmeridgian-Lower Tithonian limestone. Czorsztyn Succession, Pieniny Klippen Belt; loc. Mikušovce.

Fossils as parts of hardgrounds

Encrusting foraminifers (Tab. 6, Fig. 1-16; Tab. 7, Fig. 1-2) are the most typical constituents of hardgrounds. They are mostly simple, nubecularid taxa, but often with complex whorls and arrangement of chambers. They are common in ferroan and chloritic oncoids; in phosphatic oncoids they are rarer and the taxa occurring there are often different. It is possible that some nubecularids are symbiotically related to some ferroan bacteria. Anyway, this environment with high concentration of Fe and Mn was not toxic for them. Encrusting foraminifers are predominantly concentrated in „saddles" (depressions) of stromatolites and oncoids, where they were supposingly more sheltered during their growth. Particularly noteworthy are the encrusting foraminifers in oncoids, lacking in the surrounding deposits. The oncoids likely represented „oases" of firm substrate on which the larvae of foraminifers settled preferentially.

Slovak Geol. Mag., 10, 3 (2004), 183 – 202



Tab. 6

Fig. 1. Carpenteria cf. proteus (Earland) in a chloritic oncoid. Toarcian hardground in Adnet Limestone, Krížna Nappe, Veľká Fatra Mts.; loc. Turecká Valley.

Fig. 2. Encrusting foraminifers; right - streptospiral whorling thin continuous tubes, left - tests agglutinated by quartz silt. Chloritic oncoid in marly spotted limestone of Flaki Limestone Formation. Kysuca-Pieniny Succession, Pieniny Klippen Belt; loc. Flaki (Poland).

Fig. 3. Carpenteria cf. proteus (Earland) in a chloritic oncoid in the Adnet Limestone. Toarcian, Krížna Nappe, Veľká Fatra Mts., loc. Suchá Valley.

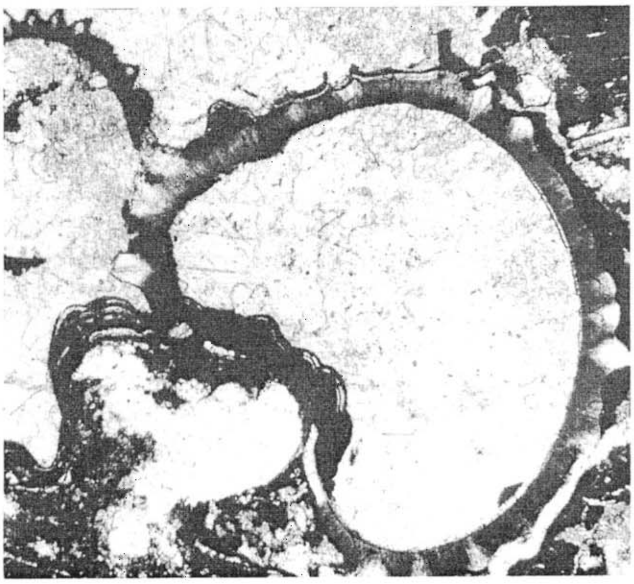
Fig. 4. Encrusting foraminifers. Loc. - as previous.

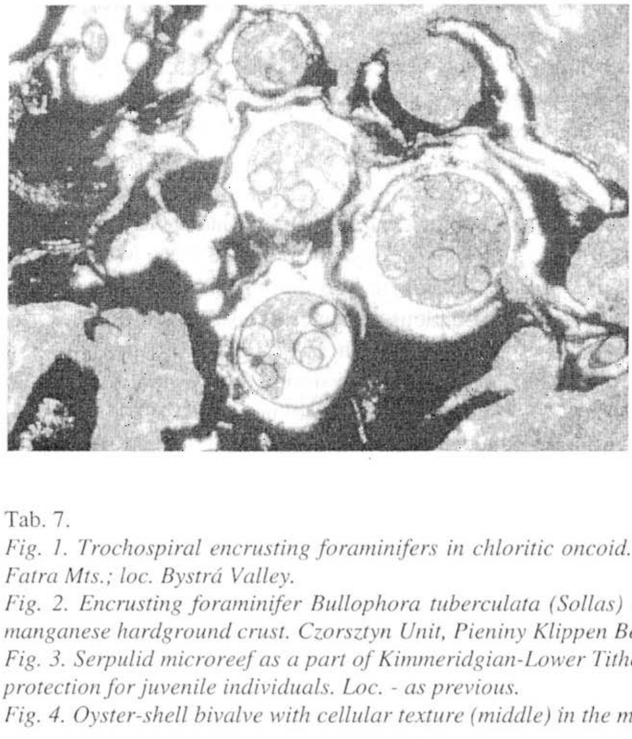
Fig. 5. Encrusting foraminifers. Upper left corner - planispiral type with undissected tube-like chambers. Loc. - see Fig. 1.

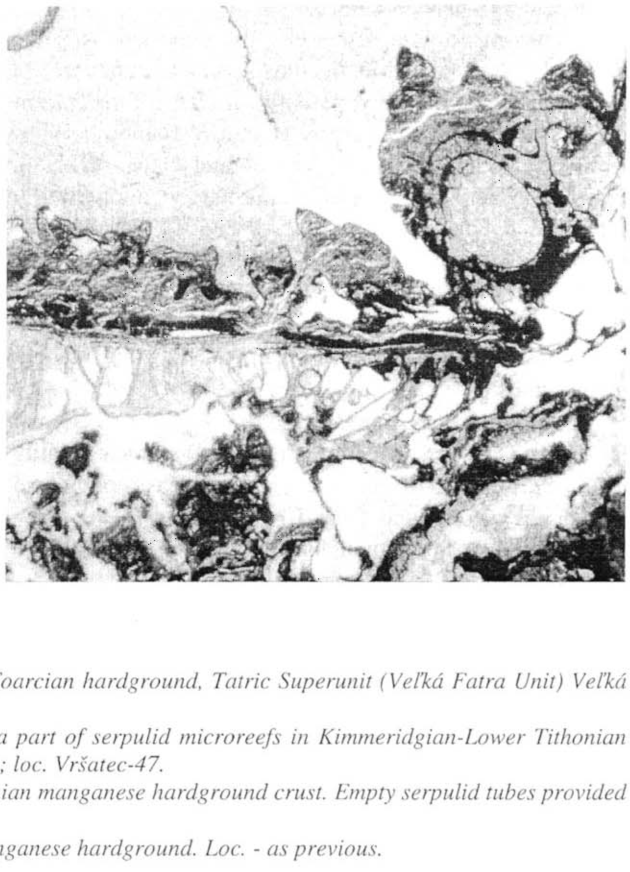
Fig. 6. Trochospiral type of an encrusting foraminifer in chloritic oncoid. Oxfordian hardground, Tatric Superunit (Malá Fatra Unit), Malá Fatra Mts.; loc. Bralo-Zázrivá Valley.

Fig. 7. Encrusting foraminifers with big proloculi in stromatolite. Lower Jurassic hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - Holý vrch.

Fig. 8. Encrusting foraminifers in Albian hardrground crust. Czorsztyn Succession, Pieniny Klippen Belt; loc. Horné Sŕnie - the topmost quarry.







Tab. 7.

Fig. 1. Trochospiral encrusting foraminifers in chloritic oncoid. Toarcian hardground, Tatric Superunit (Veľká Fatra Unit) Veľká Fatra Mts.; loc. Bystrá Valley.

Fig. 2. Encrusting foraminifer Bullophora tuberculata (Sollas) - a part of serpulid microreefs in Kimmeridgian-Lower Tithonian manganese hardground crust. Czorsztyn Unit, Pieniny Klippen Belt; loc. Vršatec-47.

Fig. 3. Serpulid microreef as a part of Kimmeridgian-Lower Tithonian manganese hardground crust. Empty serpulid tubes provided protection for juvenile individuals. Loc. - as previous.

Fig. 4. Oyster-shell bivalve with cellular texture (middle) in the manganese hardground. Loc. - as previous.

←

Fig. 9. Encrusting foraminifer from Fe-oncoid. Kimmeridgian hardground in nodular limestones, Kysuca-Pieniny Succession, Pieniny Klippen Belt; loc. Racibor Valley near Oravský Podzámok.

Fig. 10. Tubular encrusting foraminifer with irregular whorls in chloritic oncoid. Loc. - see Fig. 1.

Fig. 11. Trochospiral encrusting foraminifers in Kimmeridgian-Lower Tithonian manganese hardground. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.

Fig. 12. Trochospiral encrusting foraminifer with big proloculum, with secondary fill of umbilicum. Loc. - see Fig. 7.

Fig. 13. Encrusting foraminifer in Mn-oncoid. Loc. - as previous.

Fig. 14. Planispiral encrusting foraminifers in hardground crust. Loc. - as previous.

Fig. 15. Encrusting foraminifer in Albian hardground crust. Loc. - see Fig. 8.

Fig. 16. Tubular foraminifera with irregular whorls. Toarcian Fe-Mn hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Hrušové - Rubaninská Valley.

Slovak Geol. Mag., 10, 3 (2004), 183 – 202

The encrusting foraminifers substantially contributed to formation of the hardground crusts and oncoids. Especially in the oncoids they are so numerous that a term „mobile microreefs" may be applied for such bioconstructions. They are mostly nubecularid foraminifers, attached to the substrate by their flat bottom side, whereas the chambers are concave-up, towards the periphery of stromatolite or oncoid. Scarcely, larger foraminiferal tests agglutinated from silt quartz grains may be observed (*Tolypamminidae*, *Miniacina* sp.). Trochospiral tests with wide umbilicum probably belong to the genus *Planiinvoluta* (compare Wendt, 1969, Fig. 6), with initially stages being planispiral. Replacing of thin calcareous tests by chlorite was observed, whereas the test interiors are commonly filled with clear calcite spar, opaque Fe oxides or chlorite. This points to the fact that the tests were empty still at the beginning of the diagenesis. Rarely, encrusting foraminifers *Bullopora tuberculata* (Sollas) were found in the hardground crusts (Tab. 7, Fig. 2 - Vršatec and Bzince localities).

Encrusting foraminifers were also reported from the Recent deep-oceanic Mn oncoids. Some foraminifers in our material studied are apparently similar to *Carpenteria proteus* (Earland), reported by Bignot & Lamboy (1999) from the modern sediments of Atlantic Ocean (Tab. 6, Fig. 1, 3). Encrusting sessile foraminifers were previously identified by many authors, e.g. Wendt (1974) in manganese nodules and by Martín-Algarra & Sánchez-Navas (1995) and Martín-Algarra & Vera (1994) in phosphatic stromatolites.

Sessile bivalves occurred only sparcely in the studied hardgrounds. They are mostly oysters (Tab. 7, Fig. 4).

Ammonites were found in the Mn hardground crust at Hrušové. They are also numerous at Chtelnica locality (Tab. 8, Fig. 2). Numerous bivalves, gastropods and ammonites were found coated by manganese and phosphatic crust in an Albian hardground in Mokrá Diera Cave in Belanské Tatry Mts.

Serpulid worms were found rarely, forming microreefs for instance in Vršatec-22 locality (Tab. 7, Fig. 3).

Boring organisms. Macroscopic boring with circular cross-sections (Tab. 8, Fig. 1, 2, 5) can be attributed to **boring bivalves**. They were found at Krasín, Kamenica, Bzince, Belušské Slatiny, Chtelnica and Lednica localities. In the last mentioned locality, the borings in Tithonian limestone were filled with Albian sediment. The most common are borings after **fungi**, appearing as straight, very thin channels (1-2 μm) in bioclasts or to limestone substrate (Tab. 8, Fig. 6). Borings after **endolithic algae** are thicker (5-15 μm), usually corrugated in various directions (Tab. 8, Fig. 3-4). They are most frequently found in bivalve shells, crinoidal ossicles and foraminiferal tests (mostly of *Lenticulina*). These borings originated in euphotic zone. When occurring in deeper environment, they are allochthonous. The mentioned borings are well visible particularly after being filled with Fe-Mn minerals. Somewhat thicker borings belong to **boring polychaets** (Tab. 8, Fig. 3). In our material they are relatively scarce (for instance Solisko-Donovaly locality). Tucker & Wright (1990) mentioned boring polychaets of the genera *Trypanites* and *Polydora*.

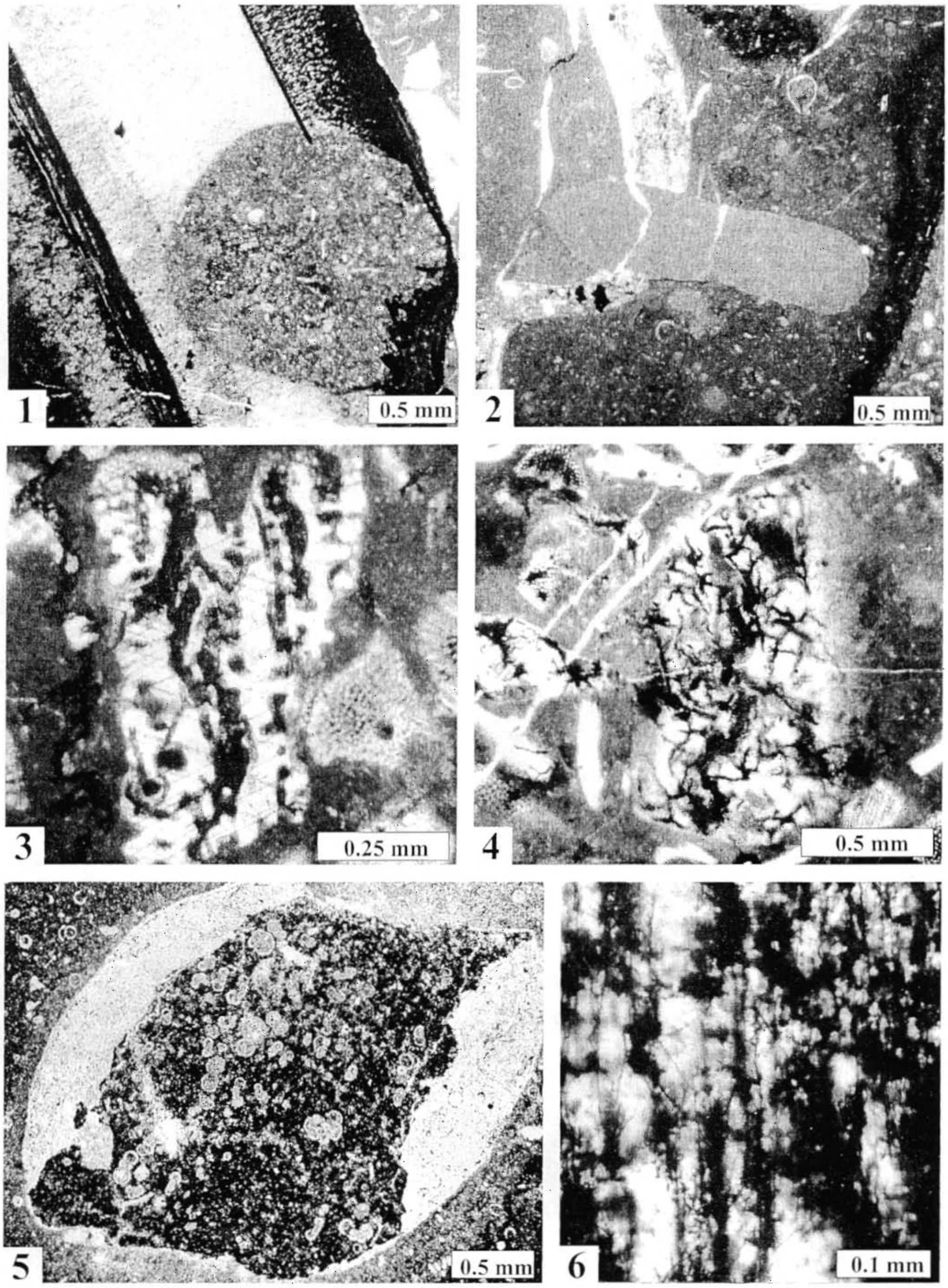
Surprisingly frequent are **planktonic microorganisms *Schizosphaerella***. To their presence in hardgrounds, a special chapter is dedicated.

Replacement of calcareous fossils by hardground minerals. Locally, replacement of tests of benthic foraminifers by manganese minerals was observed (e. g. Bolešov Valley and Vršatec-47 localities). Phosphates replaced bivalve shells in Mokrá Diera Cave and gastropod shells at Solisko-Donovaly locality. Some tests of encrusting foraminifers were replaced by chlorite at Bralo-Zázrivá Valley locality.

Schizosphaerella in hardgrounds

Thin-section study of Toarcian/Aalenian hardgrounds revealed surprisingly numerous tiny half-moon and circular cross-sections, about 0.02 mm in diameter (Tab. 9, Fig. 1-9). These hemisphaerical bodies were identified as *Schizosphaerella*, a part of nannoplankton which was ubiquitous in this period (Mattioli, 1997; Mattioli et al., 2000; Mattioli & Pittet, 2002; Pittet & Mattioli, 2002). They were not observed in the surrounding rocks. Because *Schizosphaerella* is a planktonic organism, any primary relationship with the Fe-Mn crusts is improbable. Their accumulation in the crusts can be explained by very slow deposition, or by the fact that they are better visible in the opaque material of the crusts. *Schizosphaerella* was found at the following localities: Gader Valley, Skalka above the Racibor Valley, Kornalipské Pass, Malý Zvolen near Donovaly (all in red nodular Adnet Limestone), Chtelnica (in condensed Upper Liassic limestones), Suchá Valley (in Toarcian Fe-oncoid). They were also found in the Aalenian Mn-rich claystones („manganolites") at St. Ann Chapel near Lednické Rovne, Zázrivá, and Borinka-red hut; either they were found in spotted marlstone facies („Fleckenmergel") of Upper Liassic in Silicic Superunit at Miglinc and Drieňová Hill localities. Anomalous is an occurrence in phosphatic clasts in Lower Jurassic limestones at Chtelnica locality.

No *Schizosphaerella* has been successfully isolated from the studied samples as their lithology is not suitable for nannoplankton study; therefore, no direct three-dimensional study was possible. The best preserved specimens might be identified as *Schizosphaerella punctulata* Deflandre et Dangeard, 1938. Generally, their occurrence in thin- sections may be considered as a good stratigraphic criterion for the attribution of the certain rocks to Toarcian/Aalenian time for the Western Carpathians. However, Pittet & Mattioli (2002) mentioned *Schizosphaerella punctulata* from Oxfordian of southern Germany. Hence, this taxon has wider time span. *Schizosphaerella punctulata* was also described from the Adnet Limestone of the Austrian Alps, from the type locality Adnet (Böhm et al., 1999, p. 174, Tab. 9).



Tab. 8

Fig. 1. Circular cross-section of bivalve boring in another, thicker, layered bivalve shell. The boring was filled by micrite with fine biodetritus. The shell, as a part of hardground, was later impregnated by manganese minerals that also partially corroded the hole fill of the boring. Toarcian hardground in Adnet Limestone, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Bzince pod Javorinou.

Fig. 2. Aragonitic bivalve shell was dissolved and the mold was filled with micritic sediment with tiny bioclasts; the rest was filled with sparite (white). Then, the resulting rock was bored by bivalve; the boring was filled with pure micrite. Lower Jurassic hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - NW slope of Holý vrch.

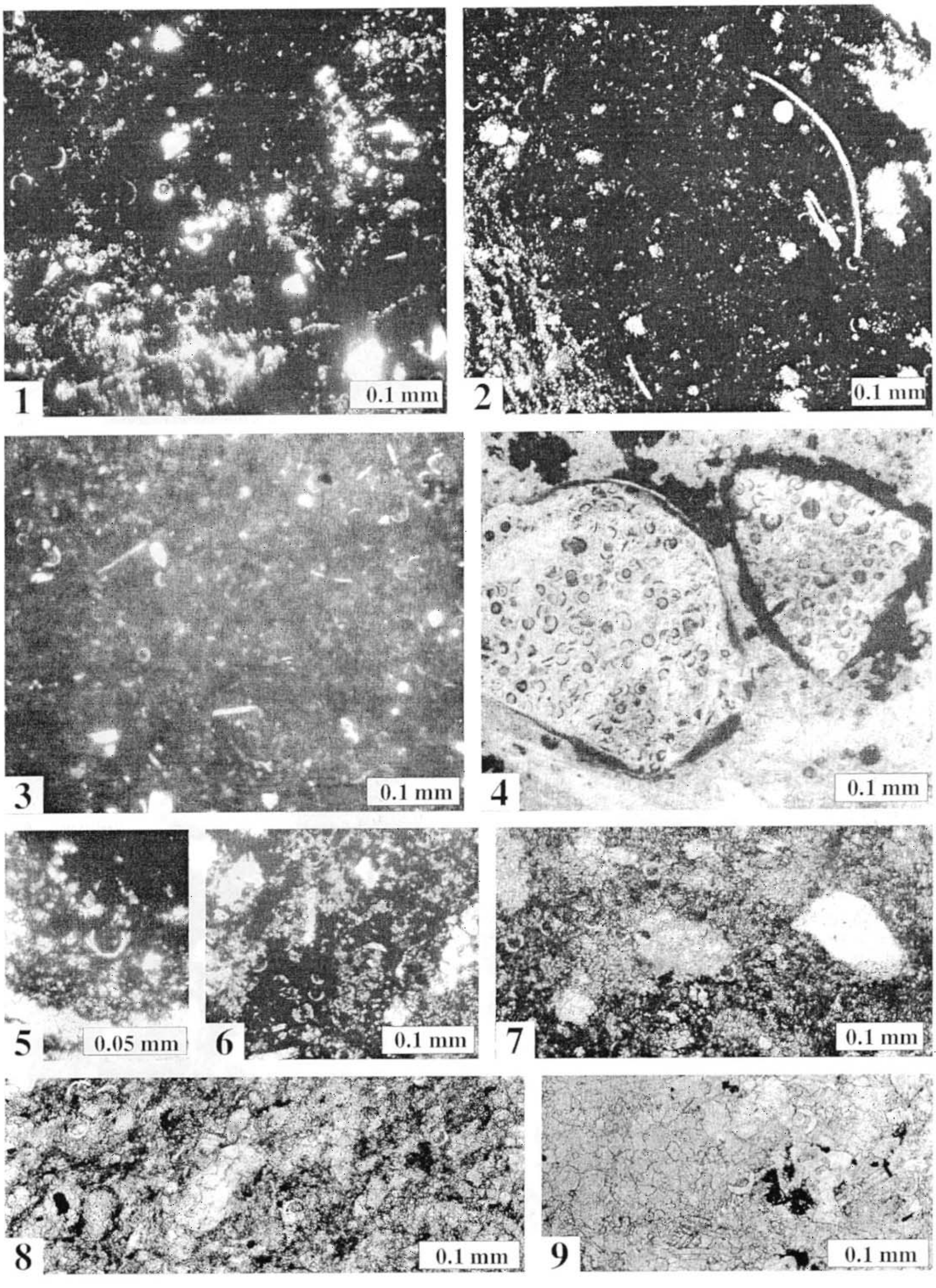
Fig. 3. Bored echinoderm ossicle. Thin, almost straight borings belong to boring algae; the thicker, undulated channels are probably product of boring polychaets. Both types of borings are filled with red ferroan oxides. Numerous boring organisms indicate condensed sedimentation and long exposition, leading to forming of the hardground. Toarcian hardground in the Adnet Limestone, Krížna Nappe, Veľká Fatra Mts.; loc. Solisko near Donovaly.

Fig. 4. Irregular, star-shaped algal borings in fragment of bivalve shell. Loc. - as previous.

Fig. 5. Bored surface of Upper Tithonian limestone with Calpionella alpina and Crassicollaria intermedia. The circular bivalve boring was filled with red Albian marlstones with Ticinella roberti. The pale margins of the filling are replaced by phosphate. Czorsztyn Succession, Pieniny Klippen Belt; loc. Lednica.

Fig. 6. Fungal borings in bivalve shell. Kimmeridgian-Lower Tithonian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec - Castle Klippe.

Slovak Geol. Mag., 10, 3 (2004), 183 – 202



Tab. 9.

Fig. 1. Problematic nannofossils Schizosphaerella punctulata Deflandre et Dangeard in manganese oncoid. Toarcian hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - Holý vrch.

Fig. 2. Four specimens of Schizosphaerella punctulata in ferroan hardground crust. Toarcian hardground in the Adnet Limestone, Krížna Nappe, Veľká Fatra Mts.; loc. Gader Valley.

Fig. 3. Schizosphaerella punctulata - half-moon and circular cross-sections in Upper Liassic condensed horizon. Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica.

Fig. 4. Phosphatic clast with numerous cross-sections of Schizosphaerella punctulata, missing in the surrounding limestone. loc. - as previous.

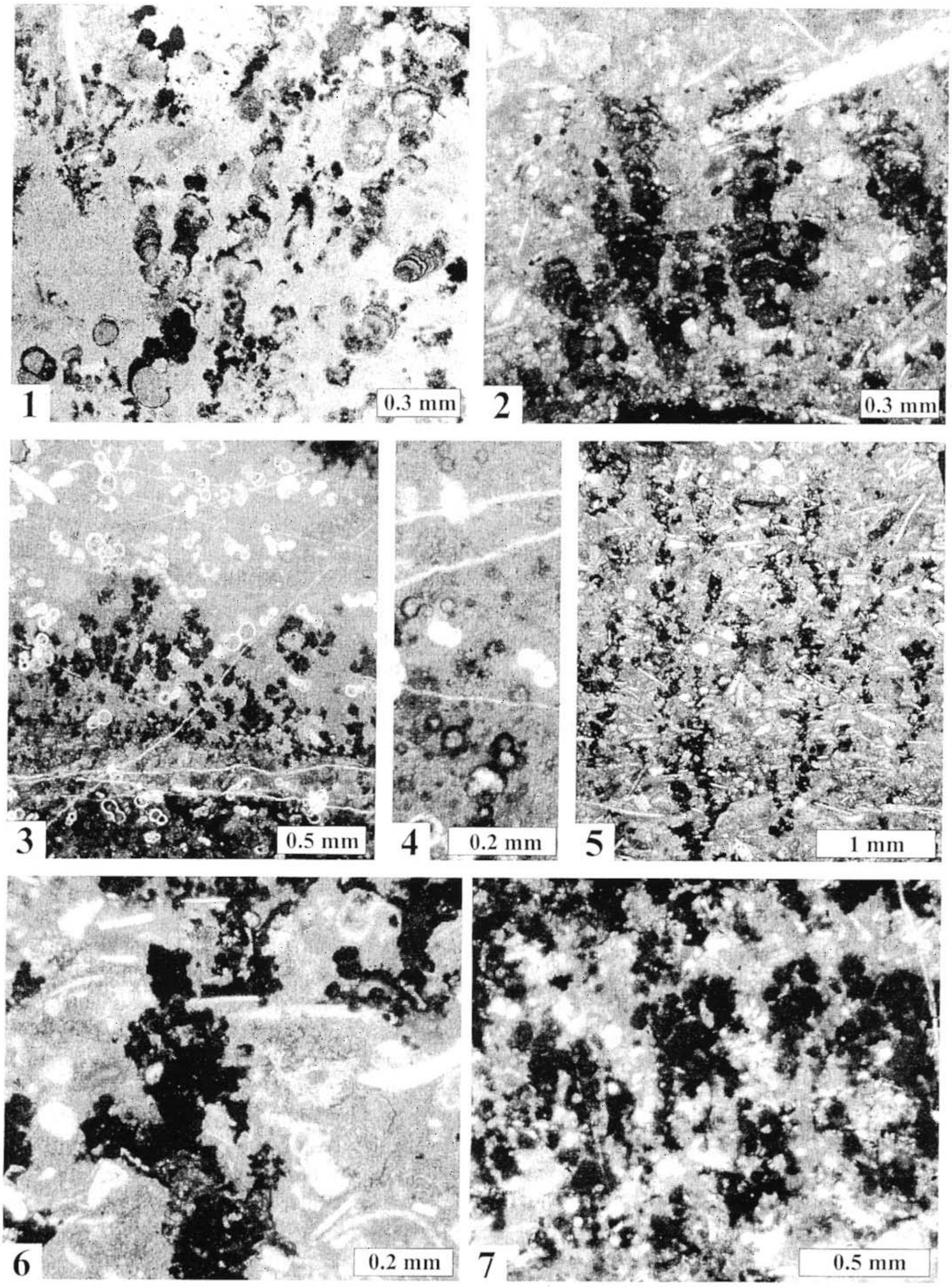
Fig. 5. Enlarged view on Schizosphaerella punctulata. Loc. - see Fig. 2.

Fig. 6. Schizosphaerella punctulata in manganese hardground. Loc. - see Fig. 3.

Fig. 7. Schizosphaerella punctulata in the core of a ferroan oncoid. Loc. - see Fig. 2.

Fig. 8. Schizosphaerella punctulata in Lower Jurassic marly spotted limestone. Slovak Karst, Silicic Superunit; loc. Miglinc Valley.

Fig. 9. Schizosphaerella punctulata in Lower Jurassic marly limestone. Slovak Karst, Silicic Superunit; loc. Drienková hora near Drnava.



Tab. 10.

Fig. 1. Frutexites - characteristic aggregates produced by microbial colonies, growing through lime sediment. these colonies, closely related to hardground crusts, commonly consist of dark half-moon concave-up (or in the direction of growth) textures. Albian hardground on Neocomian limestone. Czorsztyn Succession, Pieniny Klippen Belt; loc. Kamenica.

Fig. 2. Tiny ferroan stromatolites Frutexites, forming isolated columns, growing through the overlying carbonate sediment. Upper Liassic hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - Holý vrch.

Fig. 3. Frutexites - shrubs in the upper part of the Albian hardground. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec - Castle Klippe.

Fig. 4. Tiny circular cross-sections related to Frutexites (see the previous picture). They may also represent bacterial products (probably coccal bacteria). Loc. - as previous.

Fig. 5. Frutexites - shrubs growing through carbonate sediment with „filamentous" microfacies. Bathonian-Callovian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Drieňová near Krivoklát.

Fig. 6. Frutexites forming irregular columns, impregnated by manganese minerals. They grew through calcareous sediment, containing numerous planktonic foraminifers Globuligerina, indicating the Oxfordian age. The rock itself is probably a clast in Kimmeridgian-Lower Tithonian hardground. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.

Fig. 7 - Frutexites impregnated by Mn-oxides. Loc. - see Fig. 2.

Slovak Geol. Mag., 10, 3 (2004), 183 – 202

Frutexites

Columnar, stromatolite-like bodies, growing through overlying sediment are named *Frutexites* (Tab. 10, Fig. 1-7). They are oriented normal to stratification. Their columns are sometimes simply branching (Tab. 10, Fig. 2-3). Concave-up half-moon structures can be distinguished in the columns (Tab. 10, Fig. 1). *Frutexites* was known under various names, e. g. „ferrugineous structures with dendritic microfabrics". The term *Frutexites* was first used by Maslov (*Frutexites arboriformis*, Maslov 1960).

Frutexites belongs to pelagic stromatolites, most probably produced by bacterial colonies. Wray (1977) ranked them among problematic cyanophytes, forming shrubs as tall as 1 mm, growing normal to the bottom, arranged in clusters. They consist of incompletely branching filaments of about 50 μm in diameter (l. c.).

The deep marine, aphotic origin of *Frutexites* was also supported by Böhm & Brachert (1993). Bigger, transparent forms they found mainly in cavities. Original calcitic or aragonitic fibres were, according to them, replaced by Fe-Mn oxides and phosphates. They were formed in small cavities an interstitial pores of muddy sediments, sometimes even after beginning of the early diagenesis. In some instances, the authors (l.c.) also admit their inorganic origin. Reitner et al. (1995) considered *Frutexites* to be colonies of problematic bacteria.

Böhm & Brachert (1993) mentioned presence of *Frutexites* in Lower and Middle Jurassic of the platform part of Germany and from the Jurassic of the Eastern Alps (Adnet and Klaus limestones). Reitner et al. (1995) mentioned their presence in Cenomanian and Turonian. Szulczewski (1963) illustrated them from the Bathonian of High Tatra Mts. (l. c. Tab. V, without using the term *Frutexites*).

Frutexites structures were found by us in the Lower Jurassic, Bathonian-Callovian, Callovian-Oxfordian, Kimmeridgian-Lower Tithonian and Albian hardgrounds at the following localities: Bolešov, Drieňová hora, Kamenica, Hrušové, Bzince, Chtelnica, Vršatec-the southernmost coulisse and Vršatec-47.

Orthosparite - a very early calcite cement in mineralized hardgrounds.

Occurrence of orthosparite in hardgrounds is not very common. Usually, it fills empty spaces after leached aragonitic bivalves. Crystallization of the orthosparite is very early. A noteworthy evidence of the early orthosparite is stromatolite, growing in a void after leached ammonite shell (Tab. 11, Fig. 1). Very early crystallization of the orthosparite is also testified by its boring by fungi (Tab. 11, Fig. 2) and algae (Tab. 11, Fig. 3). Migration of the Mn compounds in form of dendrites into isometric orthosparite aggregates is visible on the Tab. 11, Fig. 3. Evidence of very early dissolution of aragonite in calcareous sediments were already provided by Palmer et al. (1988). Isometric (equant) orthosparitic cement in the Jurassic hardgrounds was also mentioned by Tucker & Wright (1990).

Pseudosparite - recrystallized and replacement calcite in hardgrounds

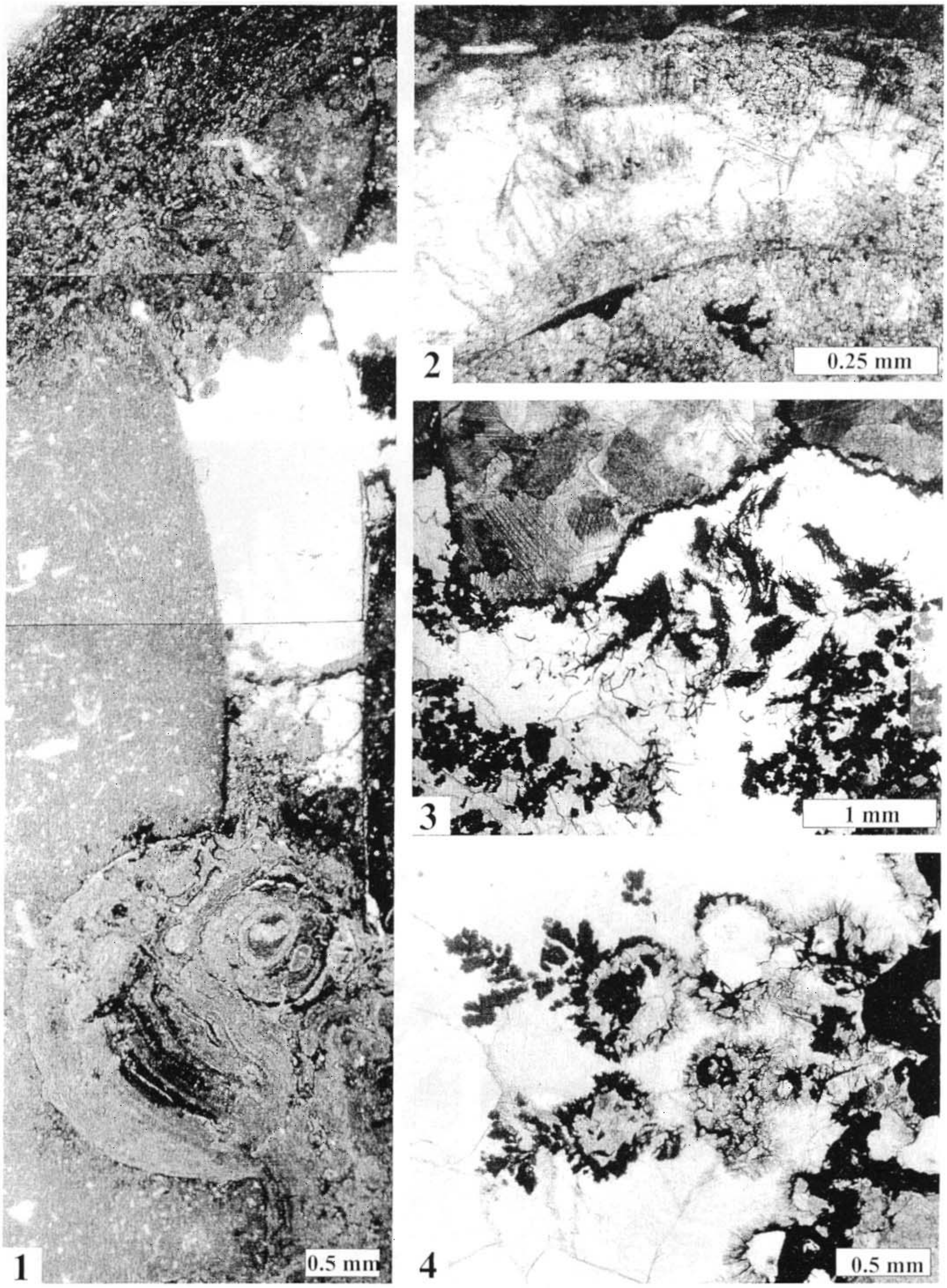
The major part of sparite in hardgrounds belongs to pseudosparite, recrystallization aggregates originated under influence of precipitation of Fe and Mn oxides and hydroxides. Mineralized crusts and stromatolites are locally completely replaced by calcite aggregates and only small relics and ghosts point to their original texture (Tab. 12, Fig. 1-6; Tab. 13, Fig. 1-6). It is a peculiar, but very common phenomenon in hardground crusts. Possible influence of migrating Fe oxides and hydroxides on calcite recrystallization was already inferred by Mišík (1968). Similar inducing effect may also be provided by migrating Mn compounds. The process usually represents an aggradational recrystallization of micritic components in mineralized crusts, Fe and Mn stromatolites and oncoids.

The process of recrystallization is evidenced by ghosts of original textures in larger, monocrystal calcite grains, where for instance the original „metacolloidal" structure of stromatolites and oncoids is only visible in inclusions and discontinuous tiny relics (Tab. 12, Fig. 3-4); considerable portion was replaced by pseudosparitic calcite. Such replacement of Mn crusts by calcite was found at Bzince locality, replacement of Mn-stromatolite at Mikušovce locality; replacements of Fe-stromatolites were observed at Egreš (46a), Vršatec-47 and Kornalipské Pass localities. Recrystallization in mineralized oncoids was described and documented by Mišík & Šucha (1997, Tab. II B-E).

Conclusions

Mineralized hardground and oncoids (haematitic, phosphatic, manganese and Fe-chloritic) are common in the Jurassic and Cretaceous sediments of the Western Carpathians (mostly on the Czorsztyn Submarine Ridge). The studied hardgrounds consist of two parts: the upper, depositional part, represented by hardground crust (mostly stromatolitic, commonly with encrusting foraminifers) and the lower, impregnation-metasomatic part that originated by replacement of underlying limestone. This part is commonly bored by fungi and cyanobacteria. The bacterial colonies sometimes continued growing through the overlying sediment, forming thus characteristic *Frutexites* aggregates. Mineralized oncoids are rich in sessile foraminifers, which completely lack in the surrounding sediments. They can be then defined as mobile microreefs. Because the encrusting foraminifers do not occur in purely calcitic oncoids, their symbiotic relationship with bacteria occurring in the Fe-Mn hardgrounds is possible. In some hardgrounds, serpulid microreefs are worth of noticing, together with common occurrence of problematic nannofossils *Schizosphaerella* in Toarcian hardgrounds.

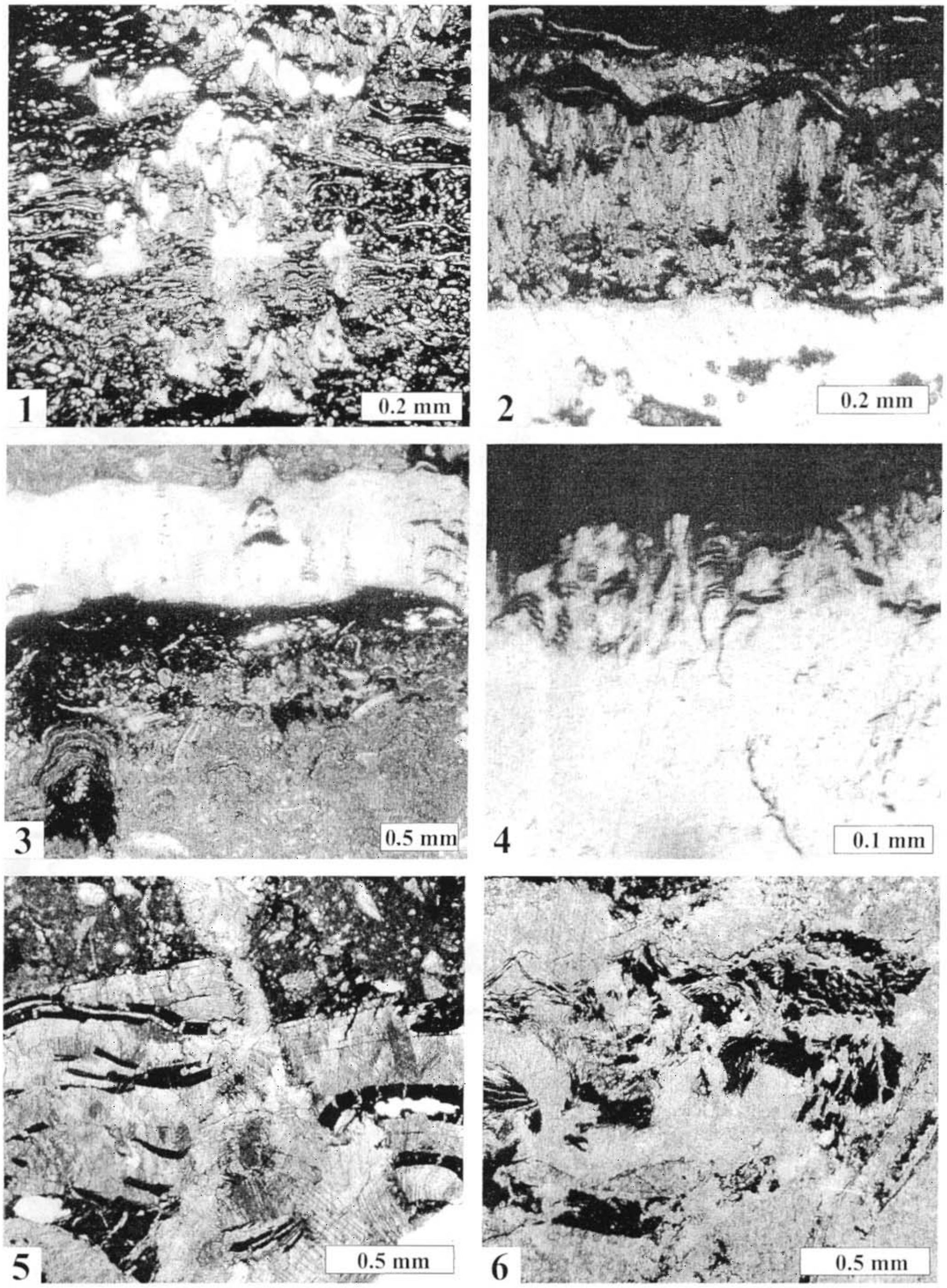
Ptygmatitic calcite veinlets occurring in some hardground crusts seem to be caused by synsedimentary plastic deformation, but they most likely originated by volume changes due to dehydratation. Some compactional deformation, however, is indicated by breakage of the



Tab. 11.

Fig. 1. Stromatolite penetrating the mold after aragonitic bivalve shell. The remaining space was filled by coarse sparitic cement. Upper Liassic hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - NW slope of Holý vrch.
Fig. 2. Mold after aragonitic gastropod shell was filled with coarse calcitic aggregate (orthosparite) and then penetrated by perpendicular, thin fungal borings. Loc. - as previous.
Fig. 3. Thin algal borings in early orthosparite, filled with Mn-oxides. The orthosparite cements a carbonate breccia in hardground. Aggregates of Mn minerals also impregnate the orthosparite. Manín Succession, Pieniny Klippen Belt (Strážovské vrchy Mts.); loc. - small quarry at the road between Belušské Slatiny and Mojtín.
Fig. 4. Sphaerical aggregates of manganese minerals, terminated with tiny dendrites in orthosparite, cementing carbonate breccia in manganese hardground. Loc. - as previous.

Slovak Geol. Mag., 10, 3 (2004), 183 – 202



Tab. 12

Fig. 1. Recrystallization of stromatolite to arborescent aggregates of pseudosparite in calcite-haematitic oncoid. The new crystals disturbed thin laminae formed by thin Bositra shells („filaments"). Upper Liassic of Silicic Superunit, Slovak Karst; loc. Kornalipské Pass near Drnava.

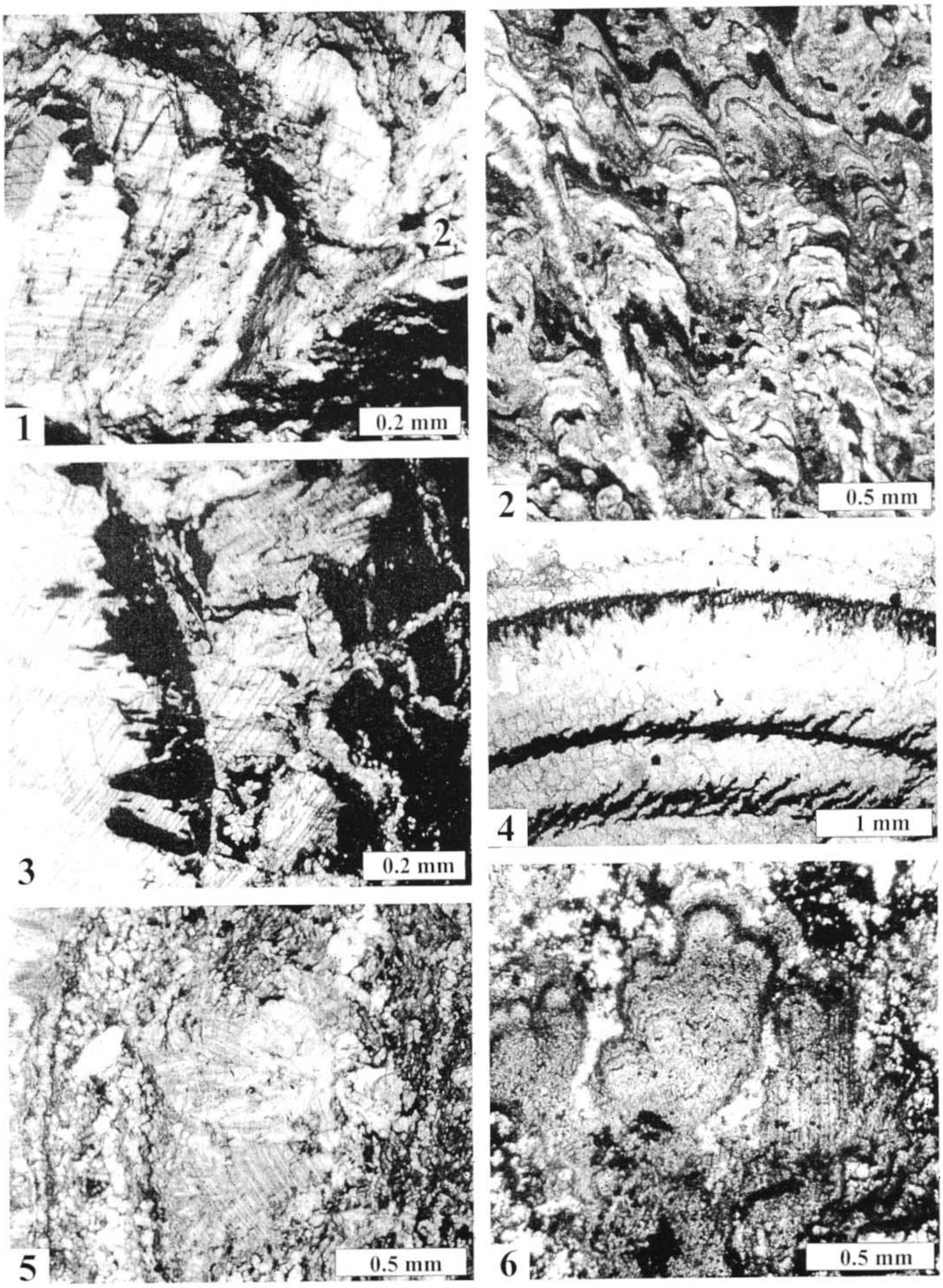
Fig. 2. Sheafy to arborescent aggregates of recrystallized calcite, pigmented by haematite in a Fe-Mn oncoid in red, pseudonodular limestone of Kozinec Formation (Lower Pliensbachian). Orava Succession, Pieniny Klippen Belt; loc. Kozinec Klippe near Zázrivá.

Fig. 3. Pseudosparitic aggregate forming a recrystallization veinlet replacing considerable portion of a Fe-stromatolite. Relics of the stromatolitic laminae in the columnal parts and the overall shape show that the veinlet did not originated by a shear, as may seem at the fist sight. Upper Liassic hardground, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Chtelnica - NW slope of Holý vrch.

Fig. 4. Relics of concentric laminae of a Fe-oncoid, replaced by newly-formed calcite (pseudosparite. Loc. - see Fig. 1.

Fig. 5. Fragments of Mn-stromatolitic laminae, disturbed by extension and broken by crystallization strength of pseudosparitic crystals. The pseudosparite replaced a considerable part of the stromatolite. Upper Toarcian hardground in nodular limestones, Nedzov Nappe, Čachtické Karpaty Mts.; loc. Bzince pod Javorinou.

Fig. 6. Mn-stromatolite, with laminae broken extension and by crystallization strength of pseudosparitic crystals. Loc. - as previous.



Tab. 13.

Fig. 1. Pseudosparite grain (recrystallized micrite) with arborescent arrangement of haematitic inclusions in a haematite-calcitic oncoid. Lower Jurassic (Toarcian) hardground, Krížna Nappe, Veľká Fatra Mts.; loc. Gader Valley.

Fig. 2. Pseudocolumnal texture in a chlorite-haematitic oncoid, formed by calcite grains (white) in the lower part. Loc. - as previous.

Fig. 3. Part of haematite-calcitic oncoid core, consisting of recrystallized belemnite guard (left edge) was bored, with boring filled with haematite. The calcite grains of the guard grew syntaxially at the expense of the oncoid. Loc. - as previous.

Fig. 4. Part of Mn-stromatolite, replaced by newly-formed calcite. Oxfordian hardground, Czorsztyn Succession, Pieniny Klippen Belt; loc. Mikušovce.

Fig. 5. Pseudosparitic grain representing an optical individual, as indicated by cleavage cracks with arborescent arrangement of haematitic inclusions. Loc. - see Fig. 1.

Fig. 6. Fe-stromatolite replaced by calcite (pseudosparite). Cleavage cracks (left) indicate that the crystal represents an optical individual. Toarcian hardground, Tatric Superunit (Kadlubek Unit), Malé Karpaty Mts.; loc. Egreš Section near a gamekeeper's cottage.

veinlets. Dehydratation shrinkage is also documented by forming of pores and cracks (alveolar and spongious textures). Possibility of submarine dehydratation was also previously discussed in literature.

Common presence of intraformational breccias and clasts indicate that condensed sedimentation was frequently related to current regime. Diagenetic processes in the studied mineralized hardgrounds were relatively rapid. Stromatolites growing in molds after leached aragonitic bivalve shells evidence a rapid aragonite leaching. Rapid forming of calcite orthosparitic cement is documented by microborings. Recrystallization under the influence of migrating Fe-colloids and hydroxide solutions is relatively common, too. It can be identified on the basis of relics of stromatolitic textures in newly formed pseudosparitic mosaic.

Acknowledgements

The authors wish to express their thanks to ??? for reviewing of the paper. Financial support was provided by by grants VEGA 1/1026/04 and 2/4095/04. R.A. also acknowledges the NATO project ST.CLG.980120: Environment, Ecology and Geologic Evolution of the Jurassic Basins.

References

Bignot, G. & Lamboy, M., 1999: Les foraminifères épibiontes à test calcaire hyalin des encroûtement polymétallique de la marge continentale au nord-ouest de la péninsules Ibérique. *Revue de Micropaleont.* (Paris), 23, 1, 3 -15.

Böhm, F. & Brachert, T.C., 1993: Deep-water stromatolites and Frutexites Maslov from Early and Middle Jurassic of S-Germany and Austria. *Facies* (Erlangen), 28, 145-168.

Böhm, F., Ebli, O., Krystyn, L., Lobitzer, H., Rakús, M. & Siblík, M., 1999: Fauna, stratigraphy and depositional environments of the Hettangian-Sinemurian (Early Jurassic) of Adnet (Salzburg, Austria). *Abh. Geol. Bundesanst.* (Wien), 56, 2, 143-271.

Donovan, R.N. & Foster, R.J., 1972: Subaqueous shrinkage cracks from the Caithness Flagstone series (Middle Devonian, northeast Scotland). *Journ. Sedim. Petrol.* (Tulsa), 42, 309-317.

Dragastan, O. & Mišík, M., 2001: Non-marine Lower Cretaceous algae and cyanobacteria from the Czorsztyn Unit, Western Carpathians. *Geol. Carpath.* (Bratislava), 52, 4, 229-237.

García-Hernándz, M., Martín-Algarra, A., Molina, J.M., Ruiz-Ortiz, P.A.& Vera, J.A., 1988: Umbrales pelágicos: metodología de estudio, tipología y significado en el análisis de cuencas. II. Congr. Geol. España, Granada, 231-240.

Martín-Algarra, A. & Sánchez-Navas, A., 1995: Phosphate stromatolites from condensed cephalopod limestones, Upper Jurassic, Southern Spain. *Sedimentology* (Oxford), 42, 893-919.

Martín-Algarra, A. & Vera, J.A., 1994: Mesozoic pelagic phosphate stromatolites from the Penibetic (Betic Cordillera, Southern Spain). In: Bertrand-Sarfati J. & Monty C. (eds.): Phanerozoic Stromatolites II. Kluwer Acad. Publ., 345-391.

Maslov, V.P., 1960: Stromatolity (ich genezis, metod izuchenia, svyaz s faciami i geologicheskoe znachenie na primere ordovika sibirskoy platformy). *Trudy geol. inst. AN SSSR* (Moscow), 41, 1-188 (in Russian).

Mattioli, E., 1997: Nannoplankton productivity and diagenesis in the rhythmically bedded Toarcian-Aalenian Fiuminata section (Umbria-Marche Apennine, central Italy). *Palaeogeogr., Palaeoclim., Palaeoecol.* (Amsterdam), 130, 113-133.

Mattioli, E., Giraud, F. & Pittet, B., 2000: The contribution of calcareous nannoplankton to carbonate production in the Jurassic. *Journ. Nannoplankt. Research* (Kyjov), 22, 2, p. 122.

Mattioli, E. & Pittet, B., 2002: Contribution of calcareous nannoplankton to carbonate deposition: a new approach applied to the Lower Jurassic of central Italy. *Marine Micropaleontology* (Amsterdam), 45, 175-190.

Mišík, M., 1966: Microfacies of the Mesozoic and Tertiary limestones of the West Carpathians. Publ. SAV, Bratislava, 1-269.

Mišík, M., 1968: Some aspects of diagenetic recrystallization in limestones. Int. Geol. Congress, Report of the XXIII. session, Czechoslovakia (Praha), Proc. of section B, 129-136.

Mišík, M., 1994: The Czorsztyn submarine ridge (Jurassic - Lower Cretaceous, Pieniny Klippen Belt): An example of a pelagic swell. *Mitt. Österr. Geol. Ges.* (Wien), 86, 133-140.

Mišík, M., Jablonský, J., Ožvoldová L. & Halásová, E., 1991: Distal turbidites with pyroclastic material in Malmian radiolarites of the Pieniny Klippen Belt (Western Carpathians). *Geol. Carpath.* (Bratislava), 42, 6, 341-360.

Mišík, M. & Rojkovič, I., 2002: Manganese mineraliztion in Lednica and Mikušovce - Pieniny Klippen Belt. *Miner. Slov.* (Košice), 34, 5-6, 303-320 (in Slovak with English summary).

Mišík, M. & Šucha, V., 1997: Chlorite and chlorite-hematite oncoids from the Jurassic limestones of the Western Carpathians, Slovakia. *Geol. Carpath.* (Bratislava), 48, 2, 85-98.

Palmer, T.J., Hudson, J.D. & Wilson, M.A., 1989: Palaeoecological evidence for early aragonite dissolution in ancient calcite seas. *Nature* (London), 335, 809-810.

Pittet, B. & Mattioli, E., 2002: The carbonate signal and calcareous nannofossil distribution in an Upper Jurassic section (Balingen-Tieringen, Late Oxfordian, southern Germany). *Palaeogeogr., Palaeoclim., Palaeoecol.* (Amsterdam), 179, 71-96.

Plummer, P.S. & Gostin, V.A., 1981: Shrinkage cracks: dessication or synaeresis. *Journ. Sedim. Petrol.* (Tulsa), 42, 309-317.

Pratt, B.R., 1998: Synaeresis cracks: subaqueous shrinkage in argillaceous sediments caused by earthquake-induced dewatering. *Sedim. Geol.* (Amsterdam), 117, 1-10.

Reitner, J., Neuweiler, F., Gautret, P., 1995: Modern and fossil automicrites: implications for mud mound genesis. In: Reitner, J. & Neuweiler, F. (eds.): Mud Mounds: A Polygenetic Spectrum of Fine-grained Carbonate Buildups. *Facies* (Erlangen), 32, 4-17.

Rojkovič, I., Aubrecht, R. & Mišík, M., 2003: Manganese hardgrounds in Jurassic limestones of the Western Carpathians. *Geologica Carpathica* (Bratislava), 54, 5, 317-328.

Szulczewski, M., 1963: Stromatolites from the High-Tatric Bathonian of the Tatra Mountains. *Acta Geol. Pol.* (Warszawa), 13, 1, 125-148.

Tucker, M.E., Wright, V.P., 1990: Carbonate sedimentology. Blackwell Science, 1-482.

Wendt, J., 1969: Foraminiferen-„Riffe“ im karnischen Hallstätter Kalk des Feuerkogels (Steiermark, Österreich). *Paläont. Z.* (Stuttgart), 43, 3-4, 177-193.

Wendt, J., 1974: Encrusting organism in deep-sea manganese nodules. In: Hsu, K.J. & Jenkyns, H.C. (eds.): Pelagic sediments; on land and under the sea. IAS Spec. publ. 1, Blackwell, 437-447.

Wray, J.L., 1977: Calcareous algae. Elsevier, Amsterdam, 1-185.