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The channel – levee sedimentary facies and their synsedimentary deformation: a case study from Huty Fm. of the Podtatranská skupina Group (Western Carpathians)

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Abstract. The paper is aimed at detailed sedimentological study of the channel – levee sedimentary facies of submarine deep-sea fan, which are documented on the Huty profile. The rhythmic, thin-bedded sandstones and claystones predominantly characterize the sedimentary record. The massive, pinching-out sandstones of the channel margin have been found in the upper part of profile. Typical evolution of the channel – levee sedimentary facies, with numerous and quickly pinching-out sandstone beds of the variable thickness, is documented. Lenticular bedding and well-developed starving ripples are very frequent. The internal fabric of beds is predominantly formed by cross-bedding and horizontal lamination. Convolute lamination is relatively common, too. Synsedimentary deformations are another evidence of the channel - levee sedimentary facies that originated during gravitational sliding of the semiconsolidated sediments from the levee slope. These synsedimentary deformations are proved by the asymmetric slump folds, clastic dykes, and by evolution of the boudinage in the sandstone beds. The direction of sedimentary sliding on the levee elevations has been reconstructed by means of original orientation of synsedimentary deformational structures. The direction of sliding is perpendicular to both local and general paleotransport direction in the western part of Central Carpathian Paleogene Basin.

Key words: Western Carpathians, Podtatranská skupina Group, Paleogene, channel – levee sedimentary facies, synsedimentary deformation

Introduction

The studied locality is situated on the northern border of the Chočské vrchy Mts. in the bedrock of the Kvačianka stream near Huty village. The outcrop is localized approximately 350 m NE of local church and 2,500 m WNW of Biela Skala elevation point (1,613 m above the sea level) (Fig. 1). The sedimentary profile is characterized by the rhythmic alternation of sandstones and claystones with ratio 1:3. In the sedimentary record, synsedimentary slump folds, clastic dykes, and boudinage of the sandstone beds were also identified. These sedimentary deformations (mainly clastic dykes) are rather seldom and from the Huty Formation have not been described. Similar clastic dikes were described by Marschalko (1965) from Šarišská vrchovina Mts.

Geological setting

From the geological point of view, the area of studied locality belongs to the Podtatranská skupina Group, which is formed by the Paleogene sediments (Gross et al., 1993). The sediments of the Podtatranská skupina Group are situated in the northern part of the Central Western Carpathians and formed the Orava, Liptov, Poprad, Podhale Basins, Levočské vrchy Mts. and Spišská Magura Mts. To the south it is bounded by the Paleozoic and Mesozoic Paleoalpine nappe systems and in the north it is separated from the Outer Western Carpathians (Flysch zone) by the Pieniny Klippen Belt (Fig. 1). The basin is developed as a forearc basin on the proximal part of the accretionary wedge.

Deposits in the Podtatranská skupina Group consist of four sedimentary formations according Gross et al. (1984, 1993; Fig. 1). The lowermost Borové Formation consists of basal terrestrial and shallow-marine transgressive deposits. The Borové Formation is covered by the Huty Formation formed by deep marine sediments of mud-rich fan. The overlying Zuberec Formation consists of rhythmical flysch deposition. The uppermost part of the Podtatranská skupina Group is formed by the Biely potok Formation, which is characterised by the thick massive sandstones of sand-rich fan.

Sedimentary record occurring on the profile corresponds to the Huty Formation of the Podtatranská skupina Group. The Huty Formation ranges from the Lower to Middle Priabonian (Gross et al., 1993), locally even to the Rupelian (Soták, 1998a, b; Olszewska a Wieczorek, 1998; Starek, 2001).

Sedimentological and facies analysis

The sediments are predominantly characterized by lithofacial sets that create geometrically limited bodies of the deep marine fan (Soták et al., 2001; Starek, 2001).

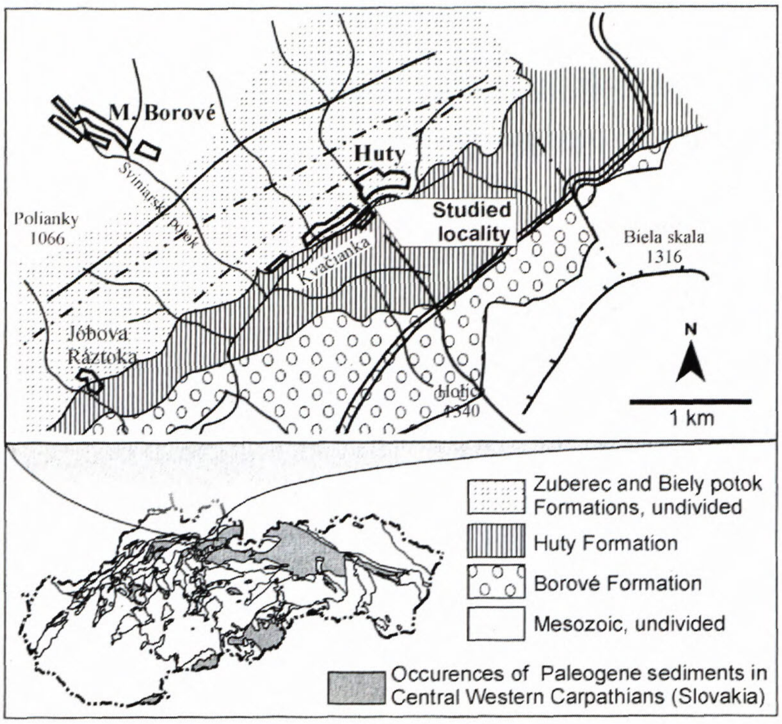

Fig. 1. Location and geological relations in neighbourhood of the Huty sedimentological profile. The profile is situated near the border between the Huty and Zuberec Formations.

The Huty profile documents facies characterizing specific part of the complex geometry of the deep marine fan (Fig. 2).

In the lower part of the profile (Fig. 2c, e) are recorded rhythmic sandstones, alternating with thin siltstones and claystones. Thick beds in this part of the profile are rare. The maximum thickness of sandstone beds is 15-20 cm. The sandstones are fine-grained, and structureless. The most common thickness of sandstones is 1-10 cm. They are fine-grained to silty and their inner structure commonly displays well-developed Tc cross-bedding, accompanied with Td, siltstone interval (Fig. 2e) (sensu Ta-e intervals of Bouma, 1962).

Convolute lamination is relatively common. In most cases, it originates by hydroplastic deformation of cross-bedding. Another common case is sandstones pinching out, as well as variable bed thickness. The beds are even locally formed by lenses and contain well-developed starving ripples (Fig. 3b). On the lower bedding planes, rare faint grooves have been observed (Fig. 2c). These NE-SW oriented structures originated by grooving of coarser material, floating in diluted flows.

This type of sediment represents facies of channel margin, levees (aggradation bars) and related inter-channel areas (Fig. 2a, b). The mentioned sediments were generated by diluted turbiditic suspensions that have overflown the channel levees. Because the levee bars are usually overflown by upper parts of turbiditic currents with lower density of material in suspension, the area of aggradation bars and mainly the overbank areas are characterized by domination of pelites. This environment is generally starving in respect to the sandy material. It is evidenced by smaller thickness and common pinching out beds, as well as presence of lensoid bedding and starving ripples.

Typical feature of levees is common occurrence of slump bodies, being formed on the edges of levee elevations towards both channel and interchannel areas. These bodies have commonly shape of slump folds, thickenings, and plastically deformed horizons, bounded by undeformed beds from the top (Nelson & Nilsen, 1984, Walker, 1985, Mutti, 1977). A slump body can be also observed at the discussed section (Fig. 2c, Fig. 3c). It consists of several dissected beds that are even folded (with fold axes 2/30° a 330/50°) which indicate a deformation in unconsolidated or only partly lithified sediment. The slump is interpreted as a result of sedimentation and motions of beds on the primary levee slope.

The highly energetic gravitation currents transported through the channels have diluted suspensions of fine sand and silt in their upper parts. These use to overflow the levees and are deposited in the inter-channel (overbank) area. A relatively common case is crewassing of the levee bar and penetration of bigger amount of channel-transported material to the inter-channel area. This is the origin of so called crevasse-splays deposits (Nelson & Nilsen, 1984, Mutti, 1977). The thick channel axis sandstone bed pinch-out over short distances into thinner bedded, finer grained deposits that onlap on the inner levee slope during infilling of the deeper parts of the channel. These sediments are termed as channel margin facies (Mutti, 1977) and can be documented in the higher part of the studied section (Fig. 2c, d). The deposits are represented by about 3 m thick layer of medium to fine-grained sandstones (Fig. 3a). Two trends of bed evolution can be seen in this part (Fig. 2c):

– The thickening-upward trend, in which upward-coarsening sandstones start to occur in otherwise typical levee facies, dominated by pelites and fine-grained sandstones. The trend documents a shift of coarse grained channel margin facies onto fine grained .levee facies. The sedimentary record displays irregular, actively prograding, and 30-60 cm thick bodies of sandstones. The beds are rarely amalgamated, mostly with homogenous bedding and platy disintegration. The lower bedding planes are predominantly flat, with rare load casts. Flute casts are not developed.

– The thinning-upward trend documents a gradually decreasing energy of a dense turbiditic current due to channel branching or avulsion. In sedimentary record, this process is documented by gradual fining and thinning of the sandstones at the expense of increasing amount of pelites.

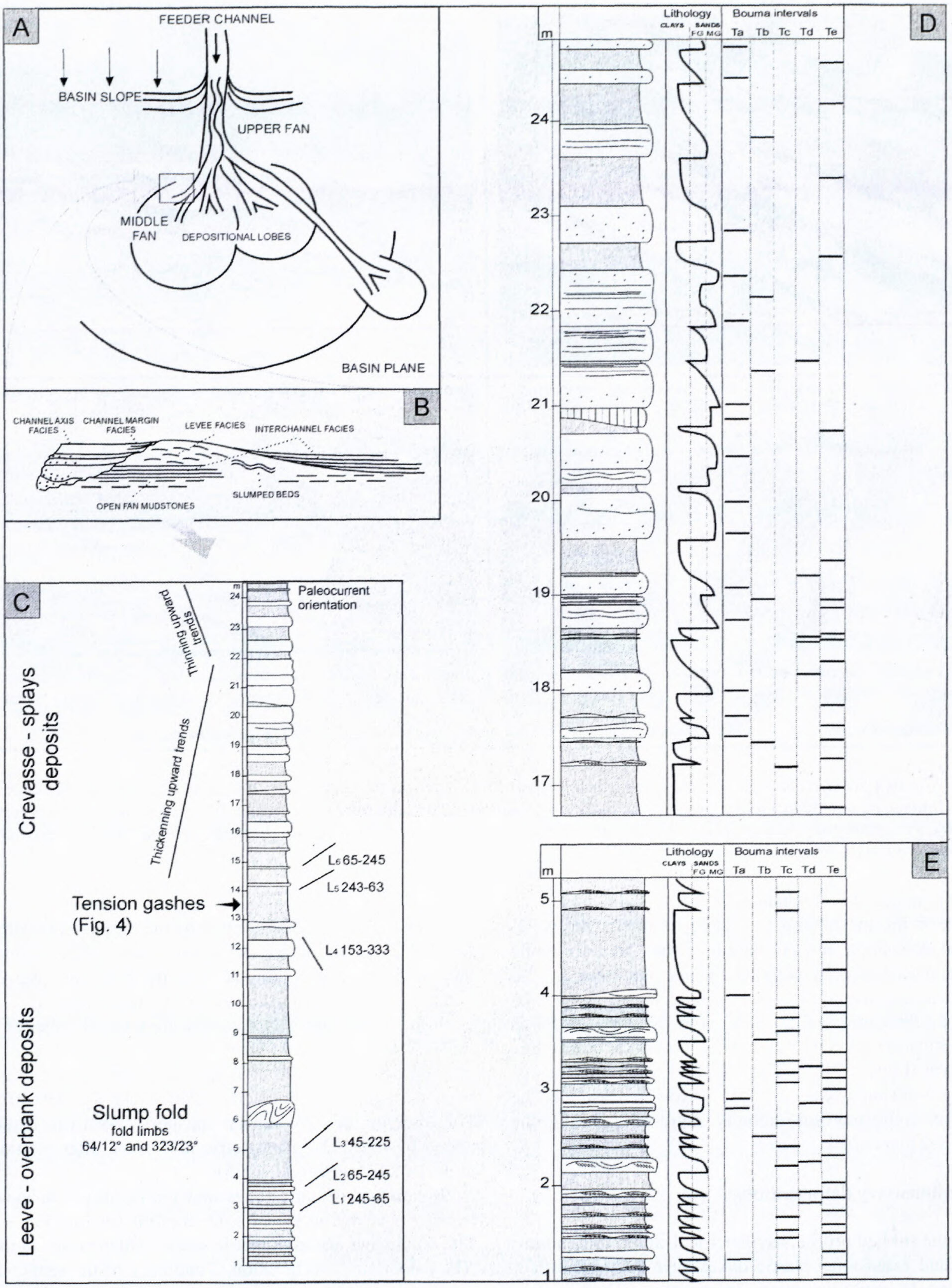

Fig. 2. The sedimentological feature of the Huty profile.

A) Position of sedimentary profile under deep marine fan (Walker, 1978); B) Schematic cross-section of the upper fan channel – levee – overbank area (Mutti, 1977); C) Schematic sedimentological log of studied outcrop and its interpretation (L – azimuth of groove casts); D, E) Detailed view of selected part of the Huty profile.

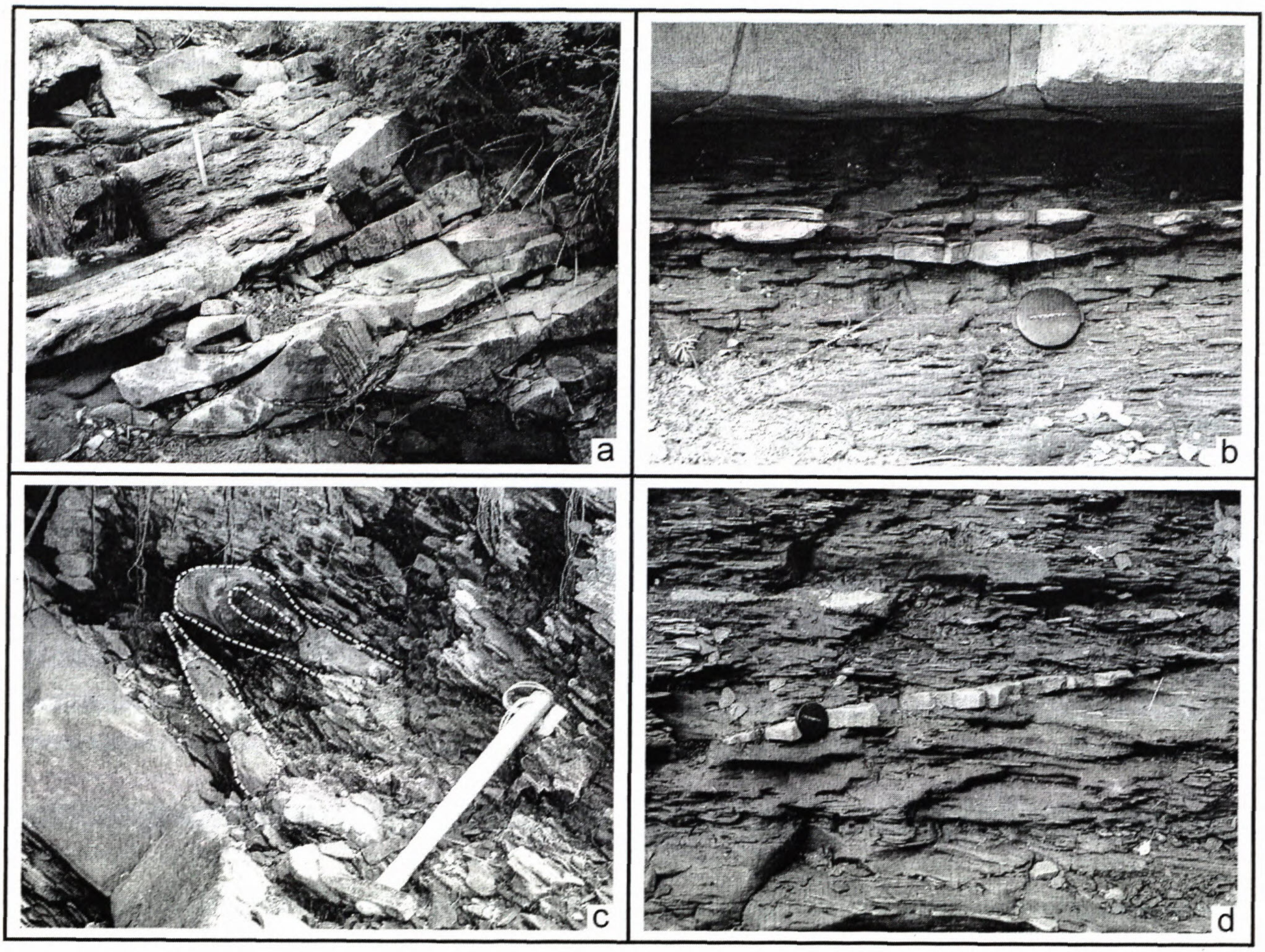

Fig. 3. The significant sedimentological and structural features in the Huty profile: a) massive, fine to medium-grained sandstones, laterally pinching out. Sedimentary facies of channel margin. b) rippled and laterally pinching out fine-grained sandstones of levee deposits. c) asymmetric slump fold and boudinage of sandstones. d) detailed view of the diagonal arranged clastic dykes and boudinage of sandstones

The migration of channel – levee sedimentary sequence is the most frequent related to autocyclic evolution of deposition fan. Formation of this sequence could be influenced also by external factors like there are sea level changes, tectonics and climatic changes. The formation of subrecent channel – levees in the Amazon fan is predominantly related to autocyclic processes during low sea level (Lopez, 2001). The sea level changes influence mainly avulsion frequency. During low sea level is the avulsion frequency substantially rapid like during the rising sea level.

Synsedimentary deformations

In the studied profile, asymmetrical slump fold, boudinage, and extensional clastic dykes have been identified, referring to synsedimentary deformation. These deformational structures, together with sedimentary textures and structures also refer to the depositional environment (Fig. 4). The observed sediments were affected by the younger deformational events, as evidenced by bedding tilted towards NW. From the point of view of this fact, the measured geological structures had to be rotated to the original position. Orientation of the rotation axis and value of the rotation are defined by the measured bedding (S_0 337/27°). The strike of bedding plane (67°) defines the orientation of rotational axis in space and dip of bedding (27°) specifies the value of rotation (Fig. 5).

In the lower part of the sedimentary profile (metres 5 to 7), a synsedimentary asymmetric slump is visible (Fig. 3c). The b-axis (36/25°) of the fold was reconstructed from the measured limbs R_1 (2/30°) and R_2 (330/50°). The direction of sedimentary transport (299°) was determined by means of asymmetric fold shape after rotation to the original position (Fig. 5).

Boudinage of sandstones and clastic dykes in claystones are visible in the 12 – 13 m of the section (Fig. 4). The boudinage has asymmetric shape, which points to the NW paleotransport direction. Boudinage of the semiconsolidate sandstones is typical feature of the synsedimentary deformation. Aditionally, two lenticular clastic dykes are developed in this part of profile. They are 70 cm long, with wedge-shaped ends (Fig. 3d, Fig. 4). The clastic dykes are en-echelon arranged with orientation T_1 324/36°, T_2 319/40° (dip direction/dip of plane). Course of the dykes is diagonal both, to the bedding of the profile

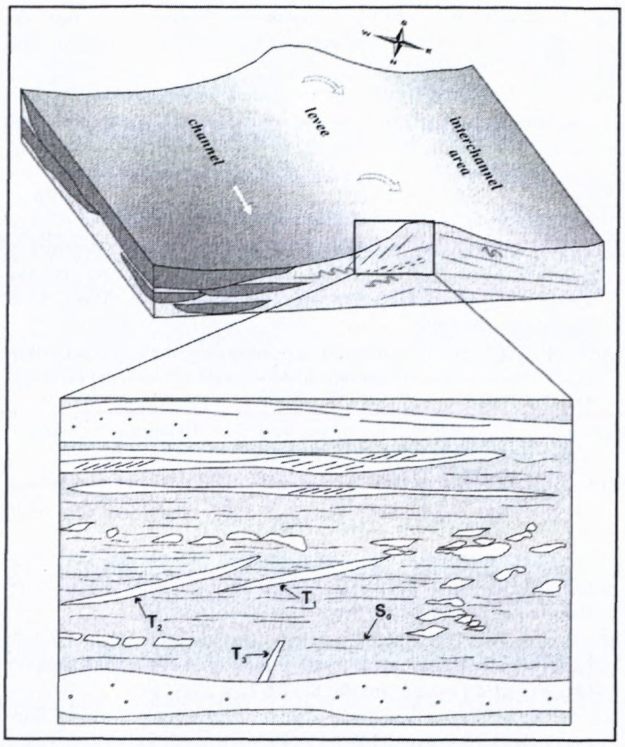

Fig. 4. Reconstruction of depositional environment from the sedimentological and structural record in the Huty profile. Detailed view in the lower part of picture represents studied clastic dykes and boudinage (redrawn from photo; the scale is 100:150 cm).

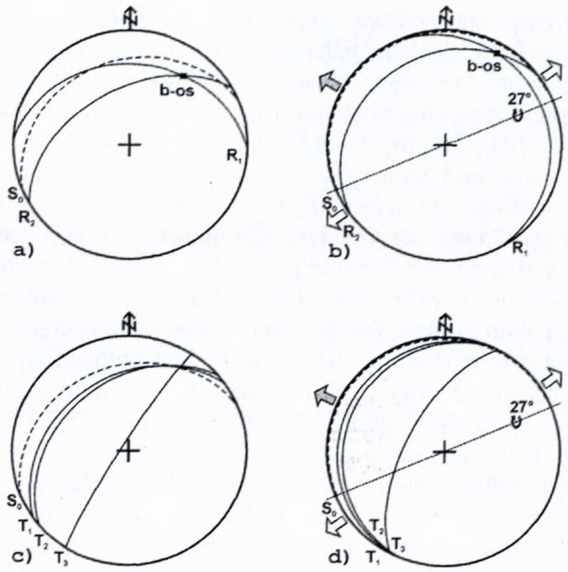

Fig. 5. Reconstruction of the original paleotransport direction from asymmetric folds and tension gashes. The planar structures have been shown by the great circle and linear structures by squares. For the diagrams have been used Lambert projection and the lower hemisphere. a) orientation of the measured structures (R_1 2/30° and R_2 330/50° fold limbs, b-axis 36/25° reconstructed from R_1 and R_2 fold limbs, S_0 337/27° bedding). b) original orientation of structures after 27° clockwise rotation around 67/0° rotational axis (original orientation of measured data R_1 64/12°, R_2 323/23° and b-axis 29/9°). Grey arrow represents sliding direction of the semiconsolidated material with 299° azimuth and white arrows are oriented parallel with local paleotransport. The azimuth of the sliding is perpendicular to the b-axis of fold. c) orientation of the measured structures (en-echelon tension gashes T_1 324/36°, T_2 319/40° and subvertical T_3 302/85° (S_0 337/27° bedding). d) original orientation of structures after 27° clockwise rotation around 67/0° rotational axis (original orientation of measured data T_1 294/11°, T_2 292/16° and T_3 297/63°). Grey arrow represents sliding direction of the semiconsolidated material with 295° azimuth and white arrows are oriented parallel with local paleotransport. The azimuth of the sliding is perpendicular to the tension gashes.

(S_0 337/27°), and to the claystones in which are they developed (Figs. 3 and 5). Except of these dykes, a subvertical clastic dyke (T_3 302/85°) has been found in the lower part of the claystone sequence, which is directly related to the underlying sandstone bed (Fig. 4). All the clastic dykes in the section are filled with fine-grained sandstone. Paleotransport direction with azimuth 295° was determined on the basis of orientation of clastic dykes, which were first rotated to the original position (Fig. 5).

Observed clastic dykes were formed under tensional stress on the low-pitched surface (Hancock, 1985; Park, 1993; Dadlez & Jaroszewski, 1994), therefore they do not represent true neptunian dykes that use to be filled either from top (Potter & Pettijohn, 1963). En-echelon arranged tension gashes in claystones originate in favourable conditions during the tensional stress and the neighbouring sands subsequently fill the joints. The tensional deformation is concentrated into highly cohesive claystones shortly after deposition. Sandstones are less cohesive as claystones and tensional stress results in the sand liquefaction and remobilisation into the open tension fractures.

Discussion and conclusions

Study of the channel - levee–overbank sedimentary facies of submarine deep-sea fan are limited in the Podtatranská skupina Group. Poorly uncovered relief, together with relative scarcity of these facies in overall volume of turbidite fan often disable observation of their distribution and spatial relationship. However, channel – levee deposits were identified from Levočské vrchy Mts. and Spišská Magura Mts. by Janočko et al. (1998) and Janočko & Jacko (1998). The Huty profile enabled interpretation of this environment on the basis of characteristic and well developed structural and textural features of the sediments. Typical feature of levee environment is dominance of pelites, thin-bedded sequences and rapid pinching out of beds. Starving ripples, lenticular bedding, slump folds and common occurrence of upper Bouma's intervals in sandstones are typical, too. This facies are associated with thick layer of medium to fine-grained sandstones in the upper part of the studied section, which we interpret as channel margin facies. Other possible interpretation point out origin of crevasse splays deposits that have similar sedimentary features to previous one.

However, paleocurrent indicators on bedding planes (parallel to general paleotransport direction) support channel margin origin of sandstones. Along with of these features, synsedimentary deformations were identified on the profile, that are manifested by tension gashes filled with sand and boudinaged sandstone beds. These types of deformations are scarce. From the ancient levee facies they were only described by Cronin et al. (2000), and clastic dykes related to slumped beds described Dzułyński & Walton (1965) from Outer Western Carpathians. Orientation of these deformation structures coincides well with the orientation of the slump folds developed on the inclined levee slopes. On the basis of such deformation structures (tension gashes, asymmetric slump folds), the NW slump direction was reconstructed. This direction is perpendicular both to the general NE trend of paleotransport in the western part of the Podtatranská skupina Group (Soták et al., 2001; Starek, 2001) and local paleotransport on studied section (Fig. 5b, d). The clastic dikes described by Marschalko (1965) are similar in origin, but there are related to basin slope failure not to levee elevations, thus their orientation is parallel to paleoslope strike.

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

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

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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

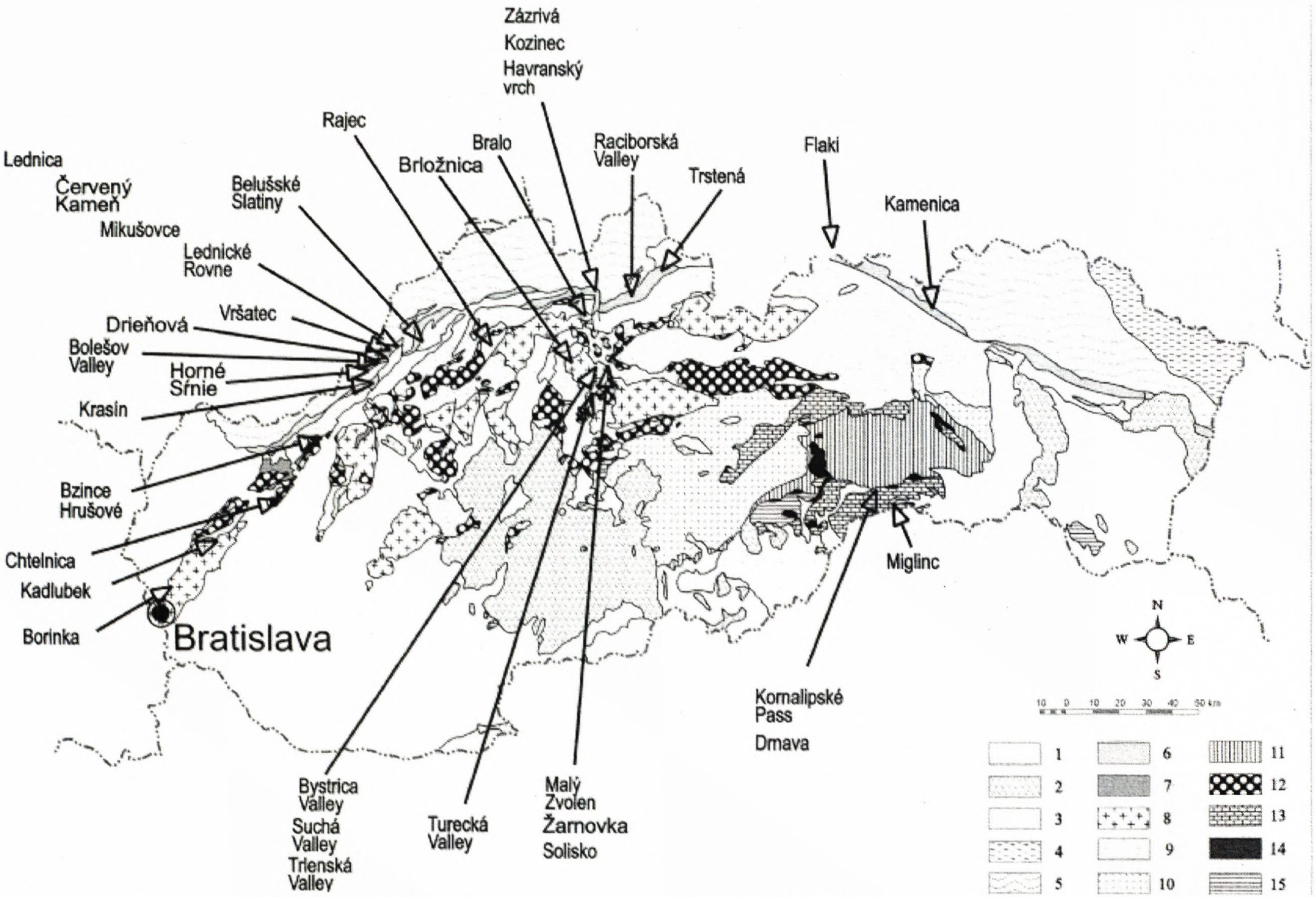


Fig. 1. Position of the sampled localities within the frames of the West Carpathian geological structures. Legend: 1. Fill of the Neogene basins, 2. Neogene volcanics, 3. Paleogene basins, 4. Outer Flysch Belt units, 5. Inner Flysch Belt units, 6. Pieniny Klippen Belt - Oravic units, 7. Senonian of the 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.

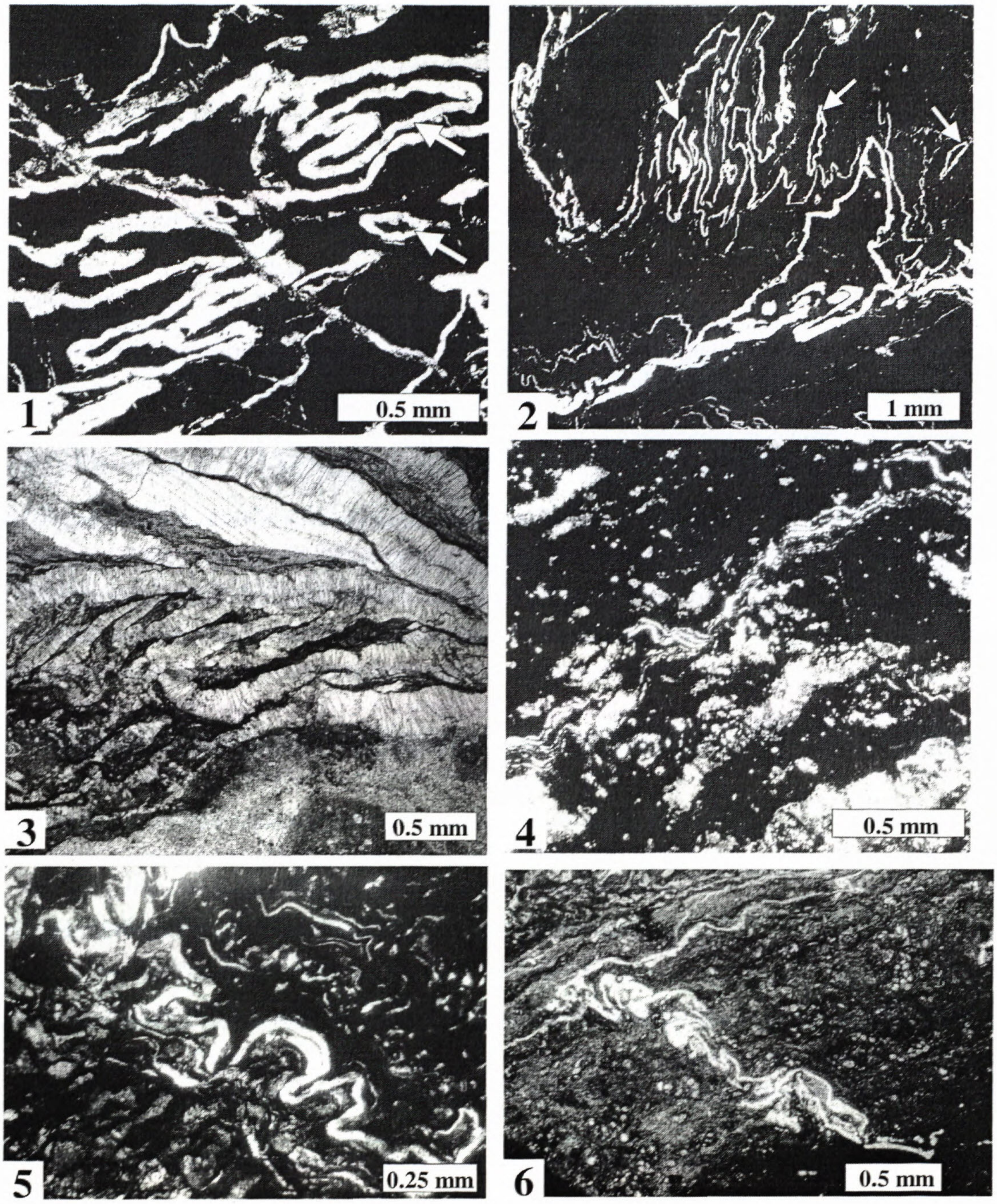
Other possible explanations of the veinlet deformation may be that the crusts were cut tangentially and slight irregularities of the surface would appear in thin sections like heavily deformed veinlets. However, this assumption is contradicted by fibrous calcite filling of some veinlets (Tab. 1, Fig. 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.

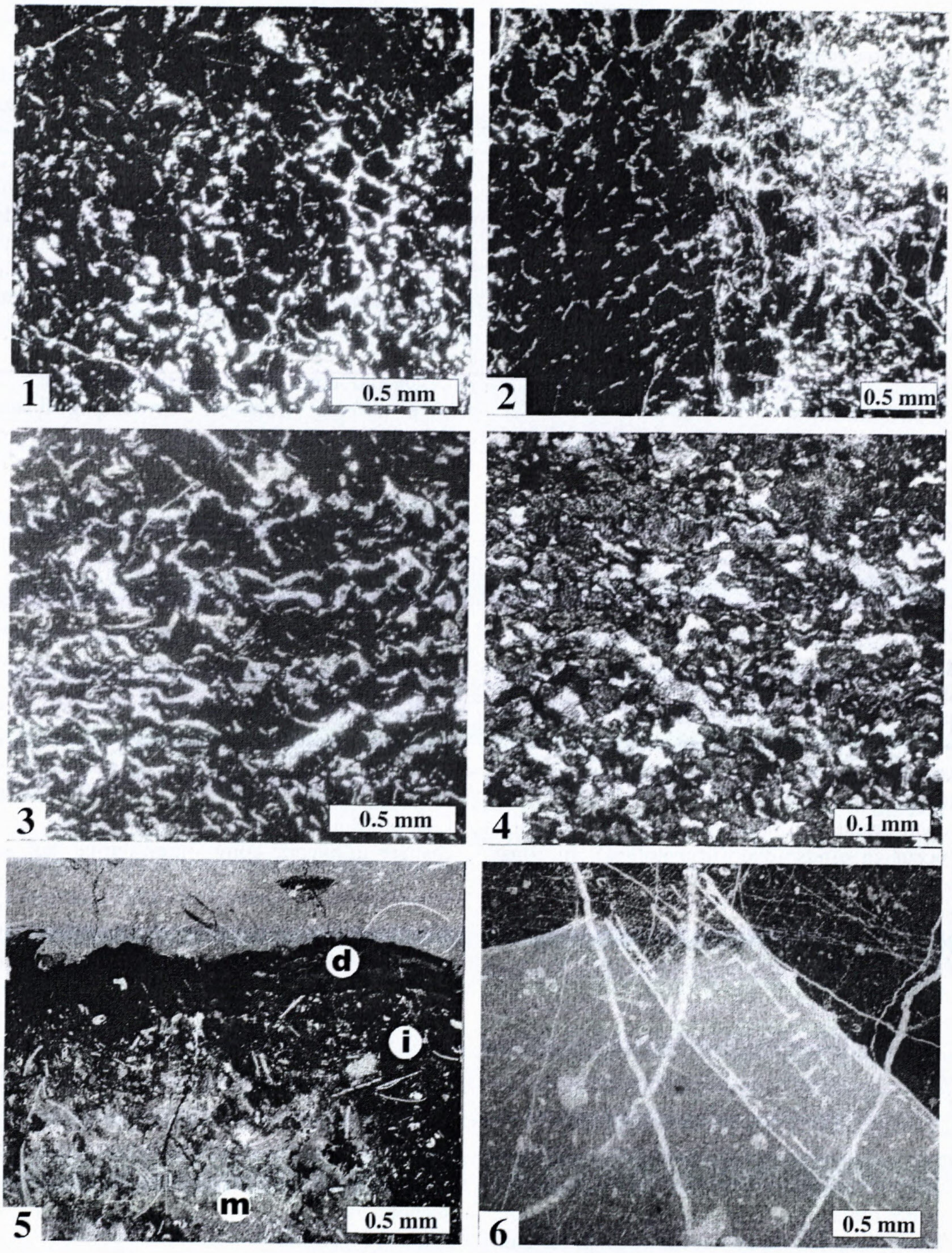
Fig. 2. The same in a different thin-section.

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)

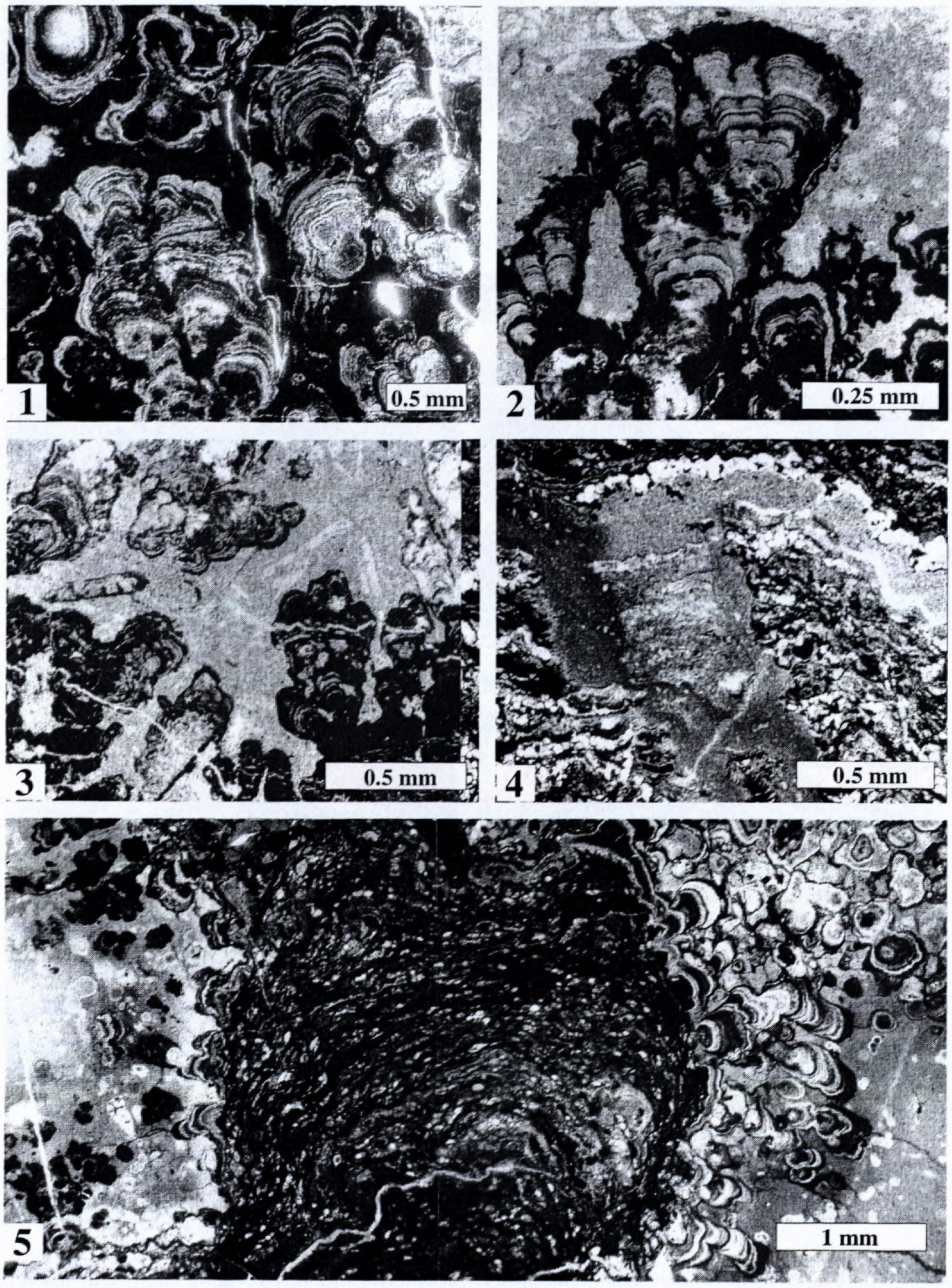
Most common are Fe-Mn oncoids; chloritic oncoids were found only in the Lower Jurassic sediments at the localities Gader Valley, Bystrica Valley, Suchá Valley, Trlenská Valley, Veľká Turecká Valley, Žarnovka, Skalka-Raciborská Valley. Upper Jurassic chlorite oncoids were found at Bralo-Zázrivá Valley. 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).

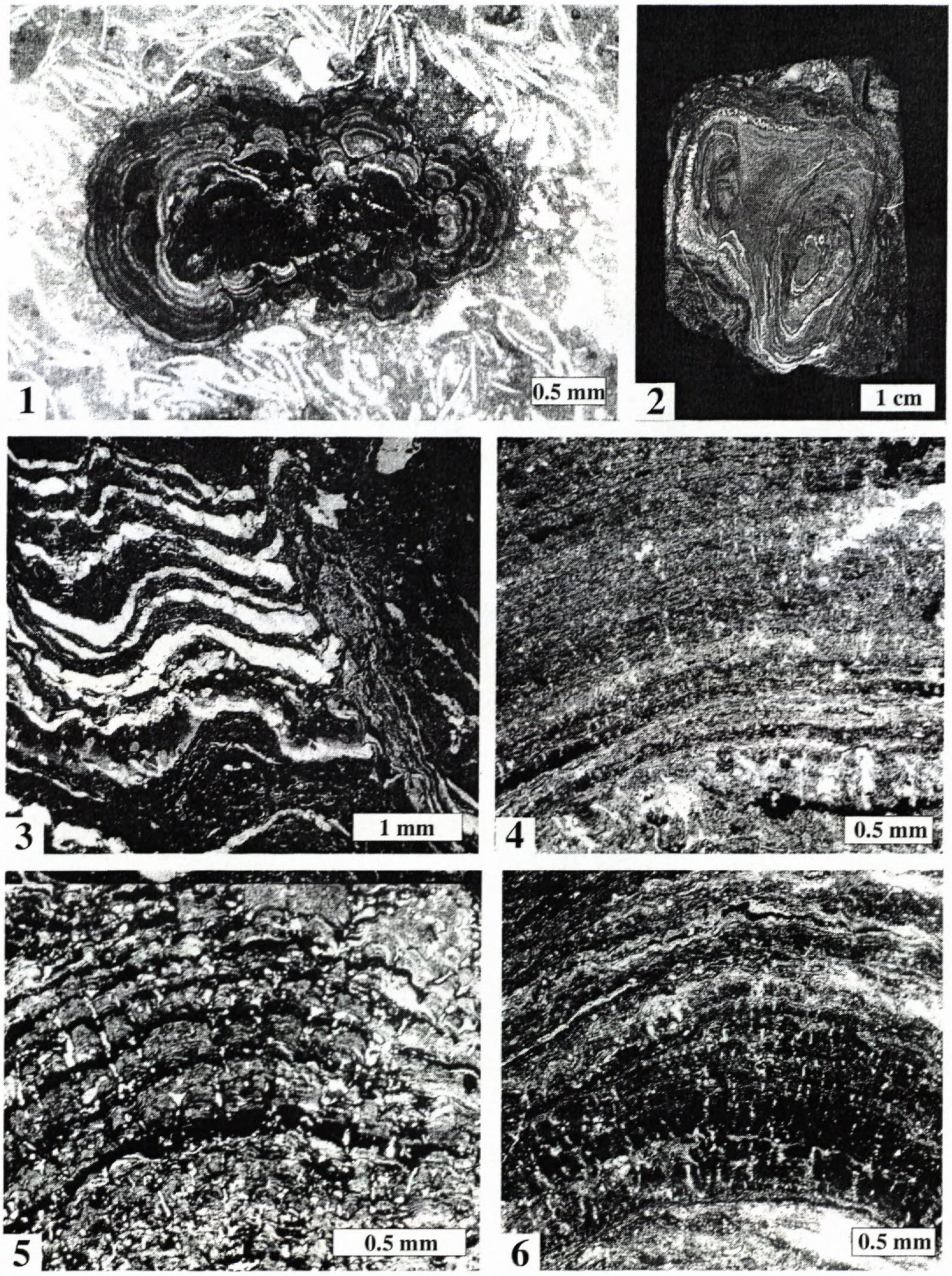
Fig. 2. Manganese stromatolite in Kimmeridgian-Lower Tithonian limestone. Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec-47.

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.

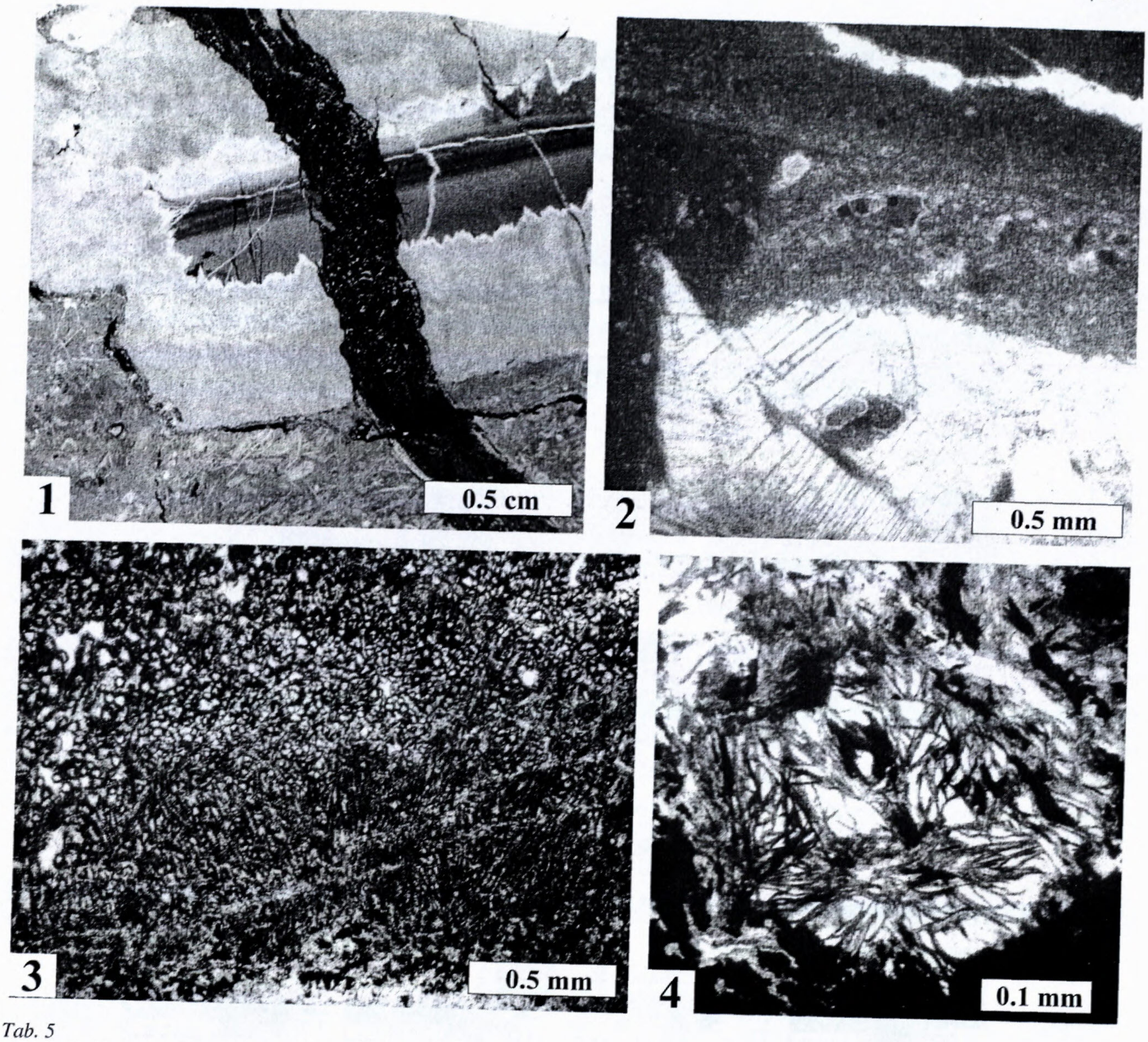
Fig. 5. Domatic Fe-stromatolite (detail of a hardground) encrusted by tiny columnal phosphatic stromatolites. The latest generation is represented by Frutexites (left part). Albian hardground in red marly pelagic limestones, Czorsztyn Succession, Pieniny Klippen Belt; loc. Vršatec - the southernmost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

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



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.

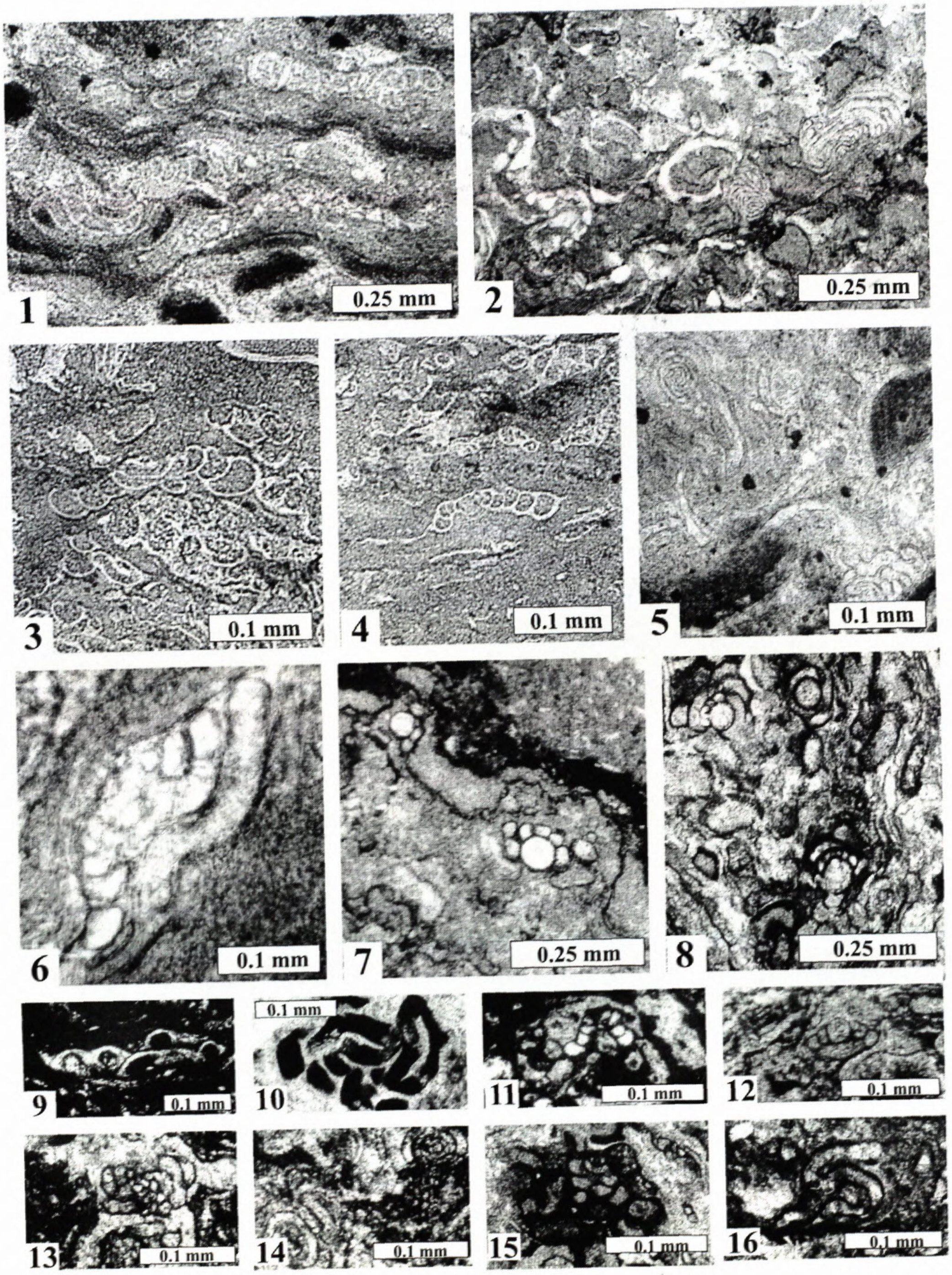
Fig. 2. Void filled by micrite containing Senonian double-keeled globotruncanid foraminifers (detail from the previous picture). Some foraminifers (bottom) are even trapped in recrystallized micrite (pseudosparite), forming the late stage of the sparitic cement.

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.



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.

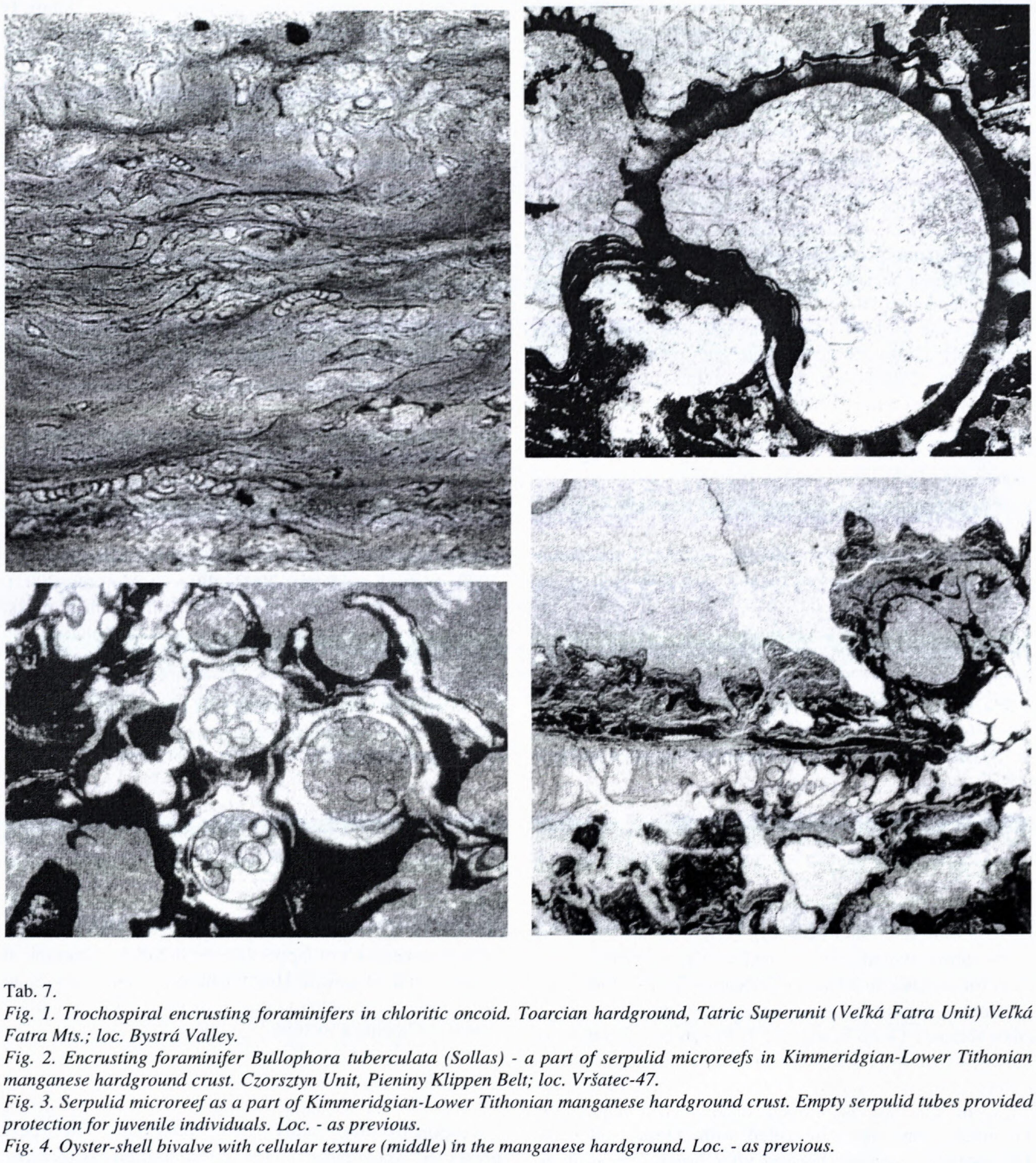
Fig. 4. Encrusting foraminifers. Loc. - as previous.

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*.

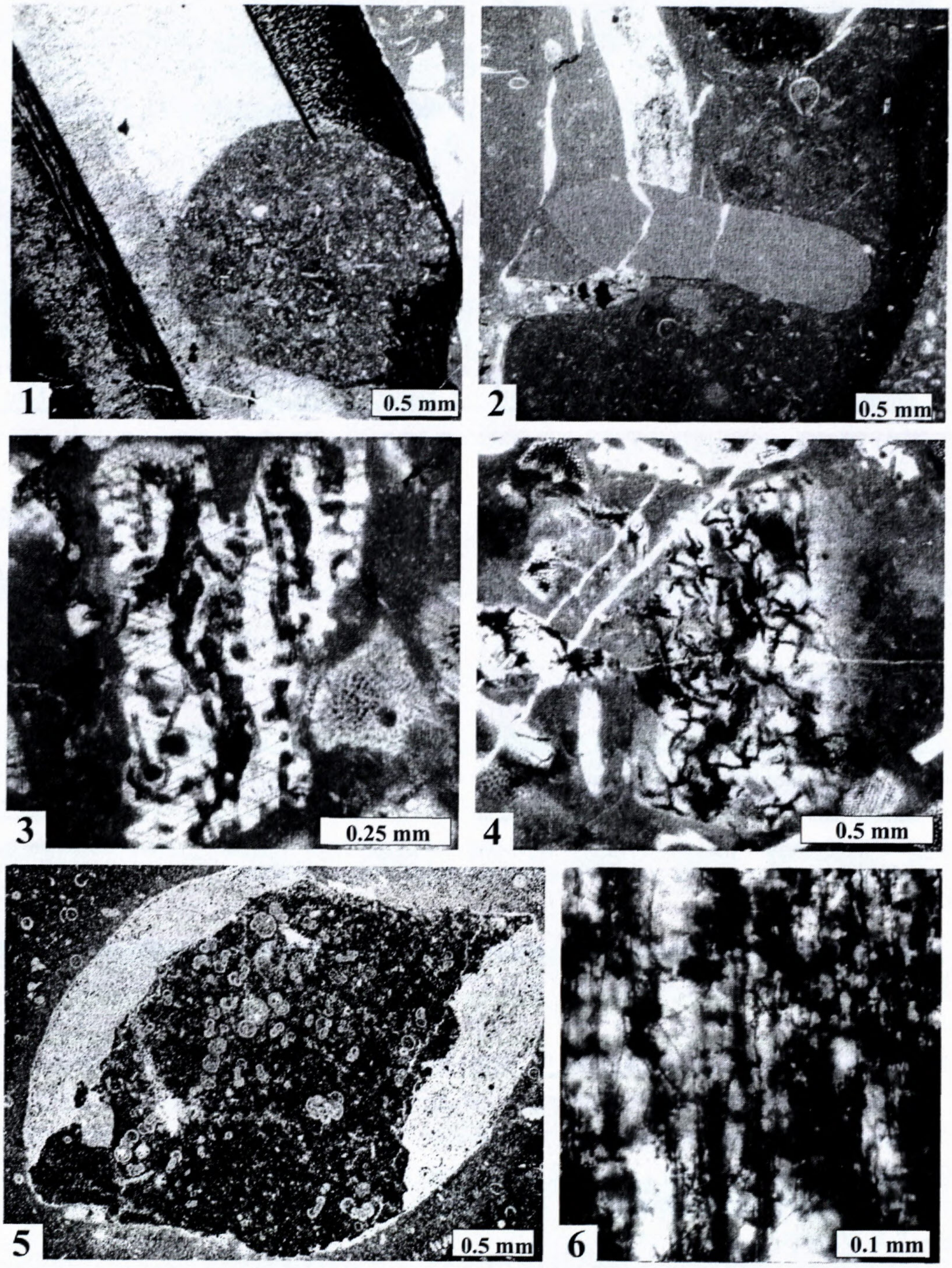
Surprisingly frequent are **planktonic microorganisms *Schizosphaerella*.** To their presence in hardgrounds, a special chapter is dedicated.

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 Borinkared 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.

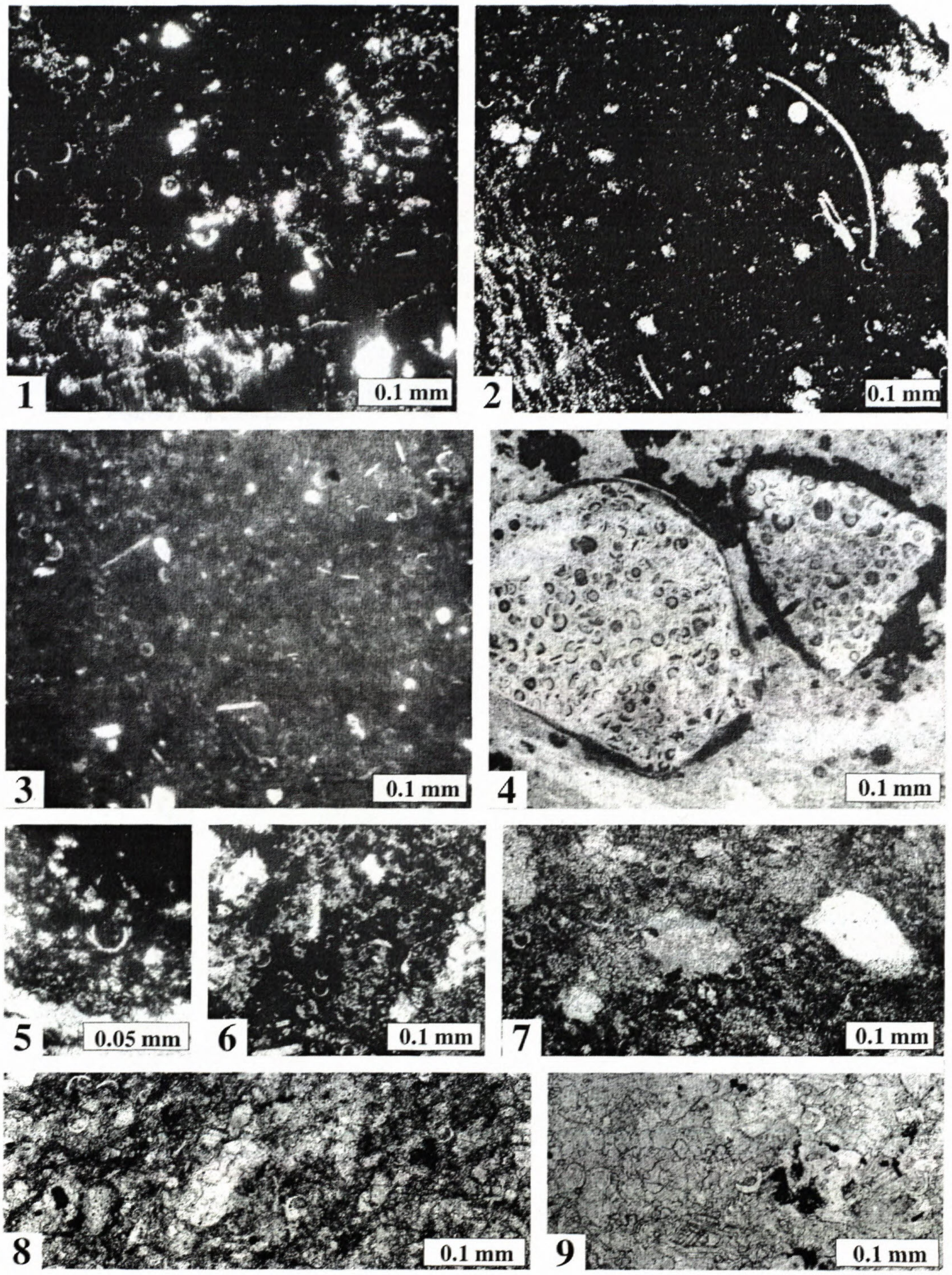
Fig. 2. Aragonitic bivalve shell was dissolved and the mold was filled with micritic sediment with tiny bioclasts; the rest was filled with sparite (white). Then, the resulting rock was bored by bivalve; the boring was filled with pure micrite. Lower Jurassic hardground, Nedzov Nappe, Čachtické Karpaty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



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.

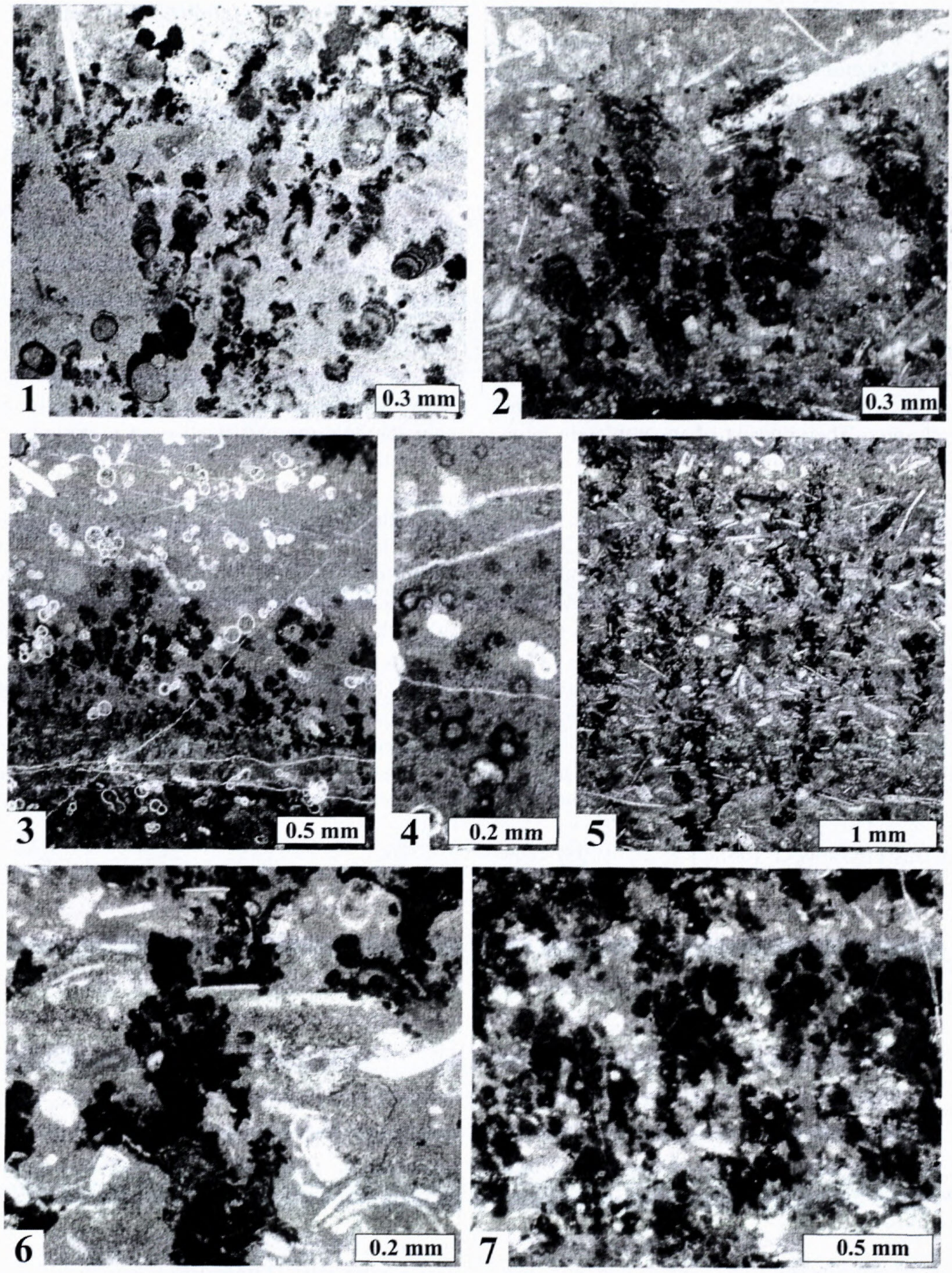
Fig. 5. Enlarged view on Schizosphaerella punctulata. Loc. - see Fig. 2.

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

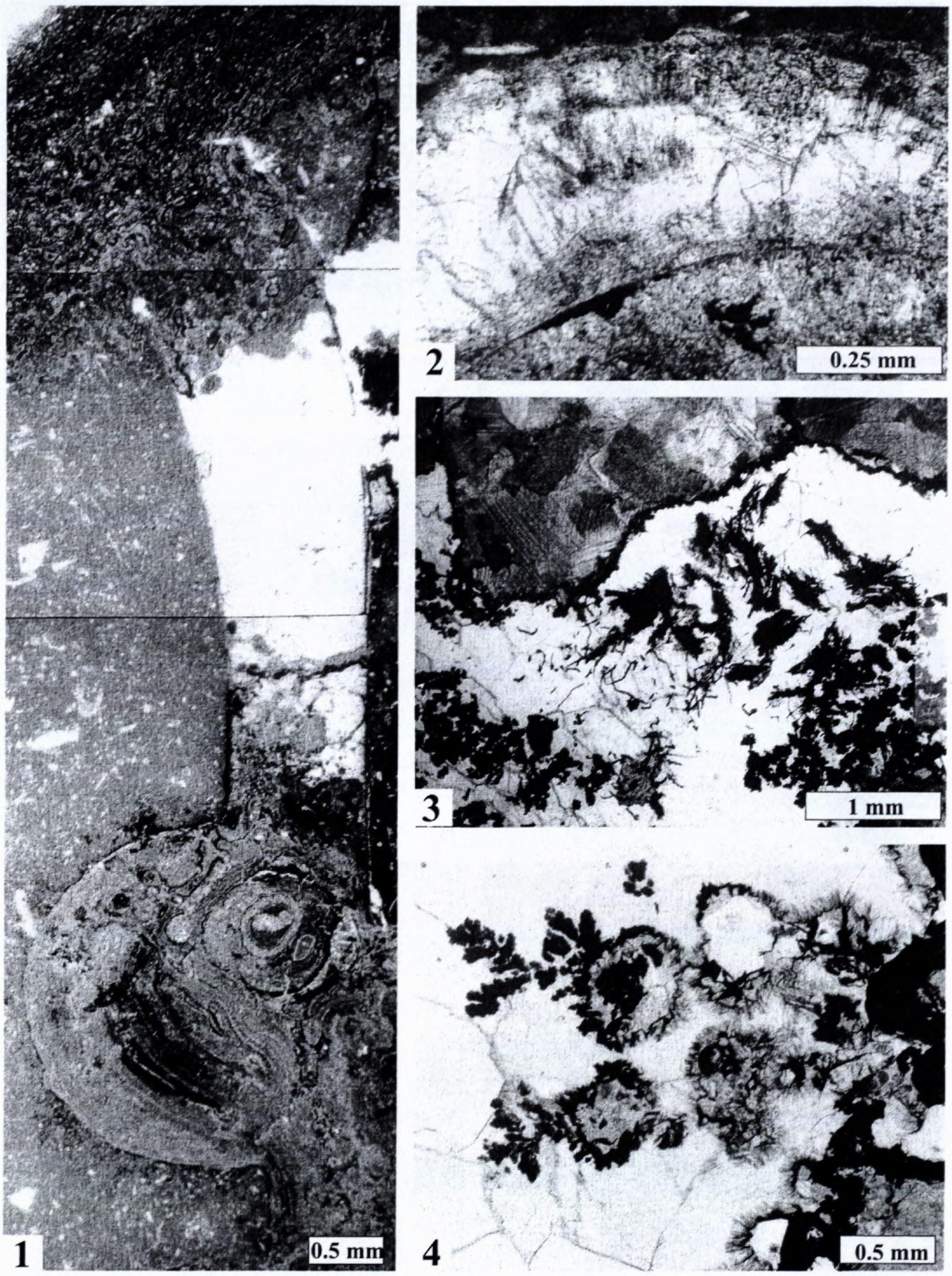
The major part of sparite in hardgrounds belongs to pseudosparite, recrystallization aggregates originated under influence of precipitation of Fe and Mn oxides and hydroxides. Mineralized crusts and stromatolites are locally completely replaced by calcite aggregates and only small relics and ghosts point 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



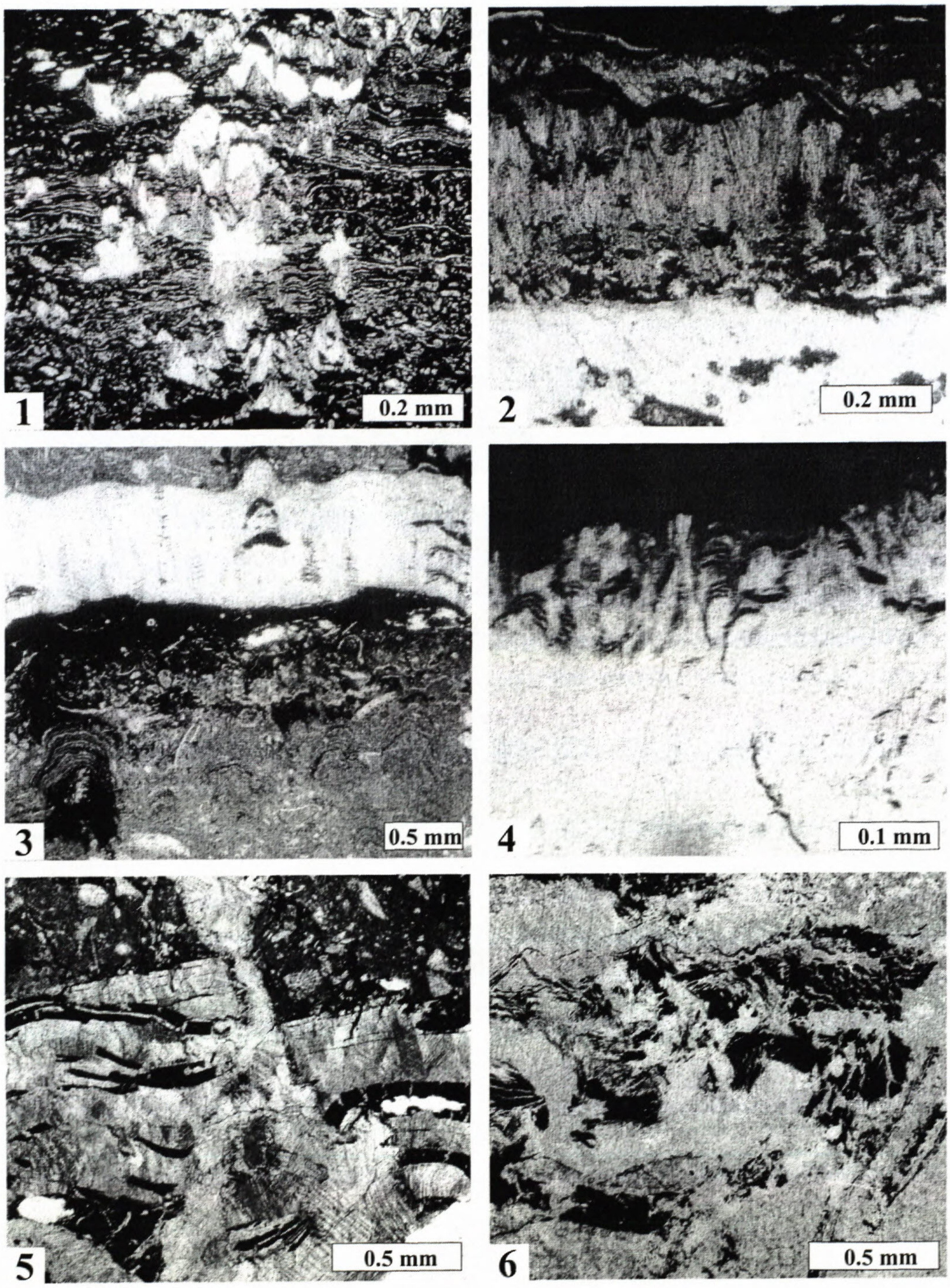
Tab. 11.

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.



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.

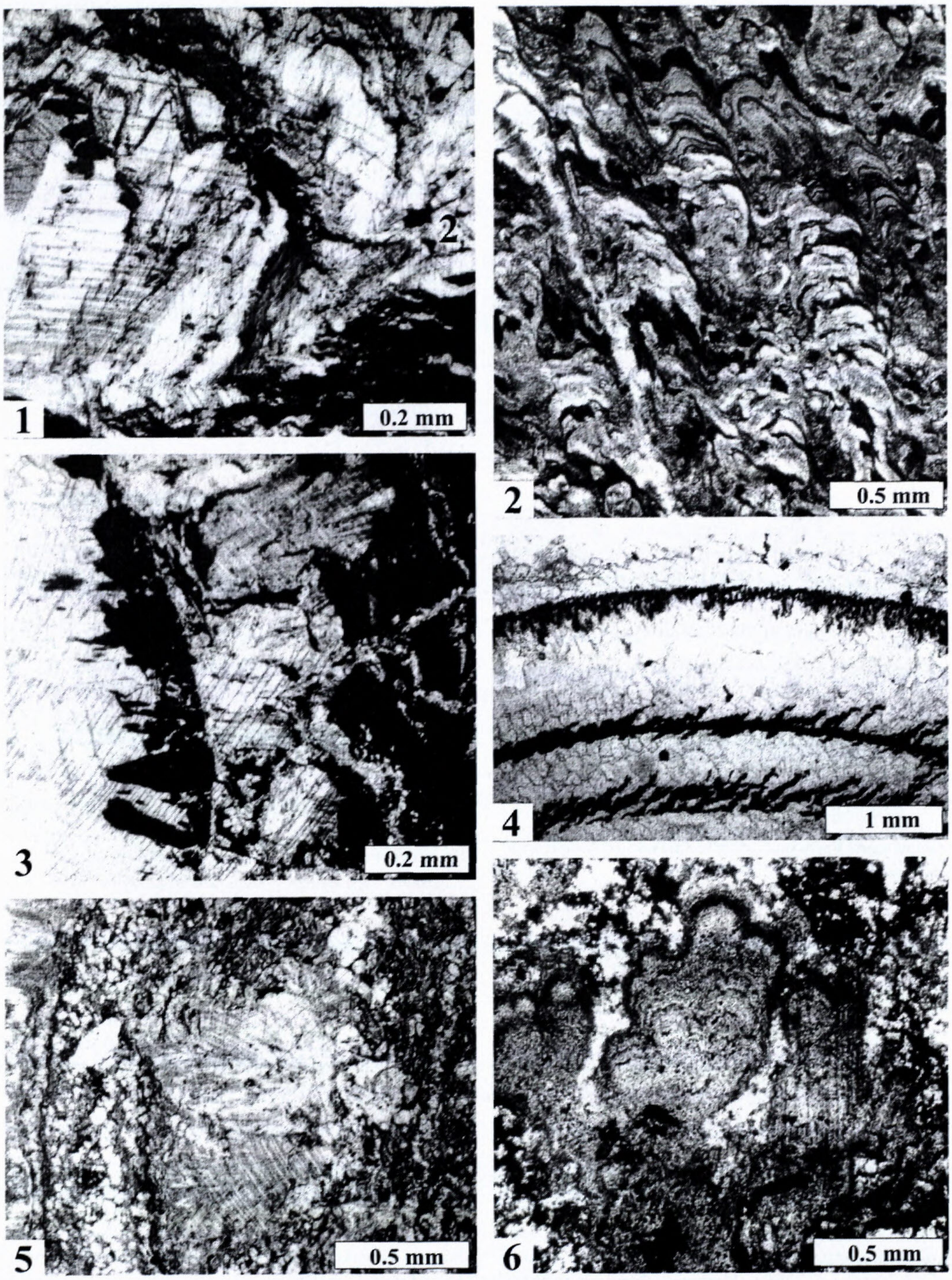
Fig. 2. Sheafy to arborescent aggregates of recrystallized calcite, pigmented by haematite in a Fe-Mn oncoid in red, pseudonodular limestone of Kozinec Formation (Lower Pliensbachian). Orava Succession, Pieniny Klippen Belt; loc. Kozinec Klippe near Zázrivá.

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

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Albian non-calcareous dinoflagellates of the Western Carpathians

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Abstract. This study describes the dinocysts extracted from Albian age sediments from western part of the Outer and Central Carpathians from the biostratigraphic viewpoint. Investigation of vertical distribution and abundance of the dinocyst taxa lead up to assign main bioevents of them, i. e. the first (FO) and last (LO) occurrences, high abundancy. The age determinations are almost exclusively based on dinoflagellate cyst ranges. Dinocyst events in the scheme described here approximates that of the ammonite zones. The study reveals that dinoflagellates prevailingly occur in the pelagic parts of the members of strata and that the assemblages of the dinoflagellates are, in principle, similar to each other. The summary is based above all on the author´s own collections in the field and his systematic study.

Key words: Western Carpathians, Albian, bioevents, biostratigraphy, dinoflagellate cyst, Czech Republic, Slovakia

Introduction

This study is a summarizing of the earlier investigation by Skupien (1997, 1999, 2002, 2003 etc.) which deal with the stratigraphic distribution of non-calcareous dinoflagellates in the Lower Cretaceous in the Czech and Slovak parts of the Western Carpathians. The Lower Cretaceous sediments contain organic-rich deposits with well preserved assemblages of palynomorphs, presenting opportunities for a more extensive palynological study of the stratigraphy of the these sediments. The dinoflagellate cyst assemblages described in this paper come from three different areas – one is situated in Czech Republic (Silesian Unit) and two are situated in Slovakia (Pieniny Klippen Belt and Manín Unit) – Fig.1.

The purpose of this paper is to document the rich assemblages of the dinocysts in the Albian and to interpret their stratigraphic significance for this region. It is nesesary to remark, that the sequence under study are without macrofaunal records. Therefore correlation of ammonite zones and dinoflagellates (which was done for Barremian – Aptian interval of the Silesian Unit, Skupien & Vašíček, 2002) are impossible.

Material

Mesozoic sedimentation in the Western Carpathians occured in two basic mega-units, which correspond to the Outer and Central Carpathians. The Outer Carpathians sedimentation basin were situated in the area of the Paleo-European Shelf in the foreland of the Bohemian Massif, the Central Carpathians on the Alpine-Carpathian microcontinent (Michalík, 1993, 1994, Vašíček et al., 1994). They were separated from each other by the oceanic crust of the Penninic, designated the Vahic Unit (Mahel', 1981) in the Carpathians. The later phases of the Alpine folding in the Upper Cretaceous (in the Central Carpathians) and in the Tetriary (in the Outer Carpathians) led to the complex nappe structure of both these units, which became part of the extensive Alpine mountain belt. The Lower Cretaceous sediments in the Carpathian nappes are usually only incompletely preserved.

The studied sections are situated in the Silesian Unit of the Outer Carpathians (Czech Republic), the Kysuca and Klape Units of the Pieniny Klippen Belt and the Manín Unit of the Central Western Carpathians (Slovakia) – Fig. 1.

The Silesian Unit is formed by the hemipelagic and flysch deposits of the Upper Jurassic to Miocene age. The Albian of Godula development (basinal setting) of this unit is represented by the Lhoty Formation. The Lhoty Formation is composed of dark grey and green-grey calcareous and non-calcareous claystones spotted with chondrites, thin bedded sandstones alternated with claystones and spongiolite cherts (Menčík et al., 1983). The Lhoty Formation is underlain by dark grey to black non-calcareous claystones of the Veřovice Formation (Upper Aptian) formed during the maximum of the Lower Cretaceous anoxic event. The boundary of the Lhoty Formation with the owerlying Mazak Formation (Cenomanian) is gradational. This formation consists of an alternation of non-calcareous red-grey and green claystones with thin-bedded glauconitic sandstones (Roth, 1980, Skupien & Vašíček, 2003).

The Albian deposits of the Silesian Unit have been studied biostratigraphically using mainly foraminifera (Hanzlíková, 1963, 1966).

The dinoflagellate cyst assemblages described in this paper come from three sections (Fig. 1): Bystrá, located south-east of the town Frenštát pod Radhoštěm (Skupien,

Slovak Geol. Mag., 10, 3 (2004),203 – 214

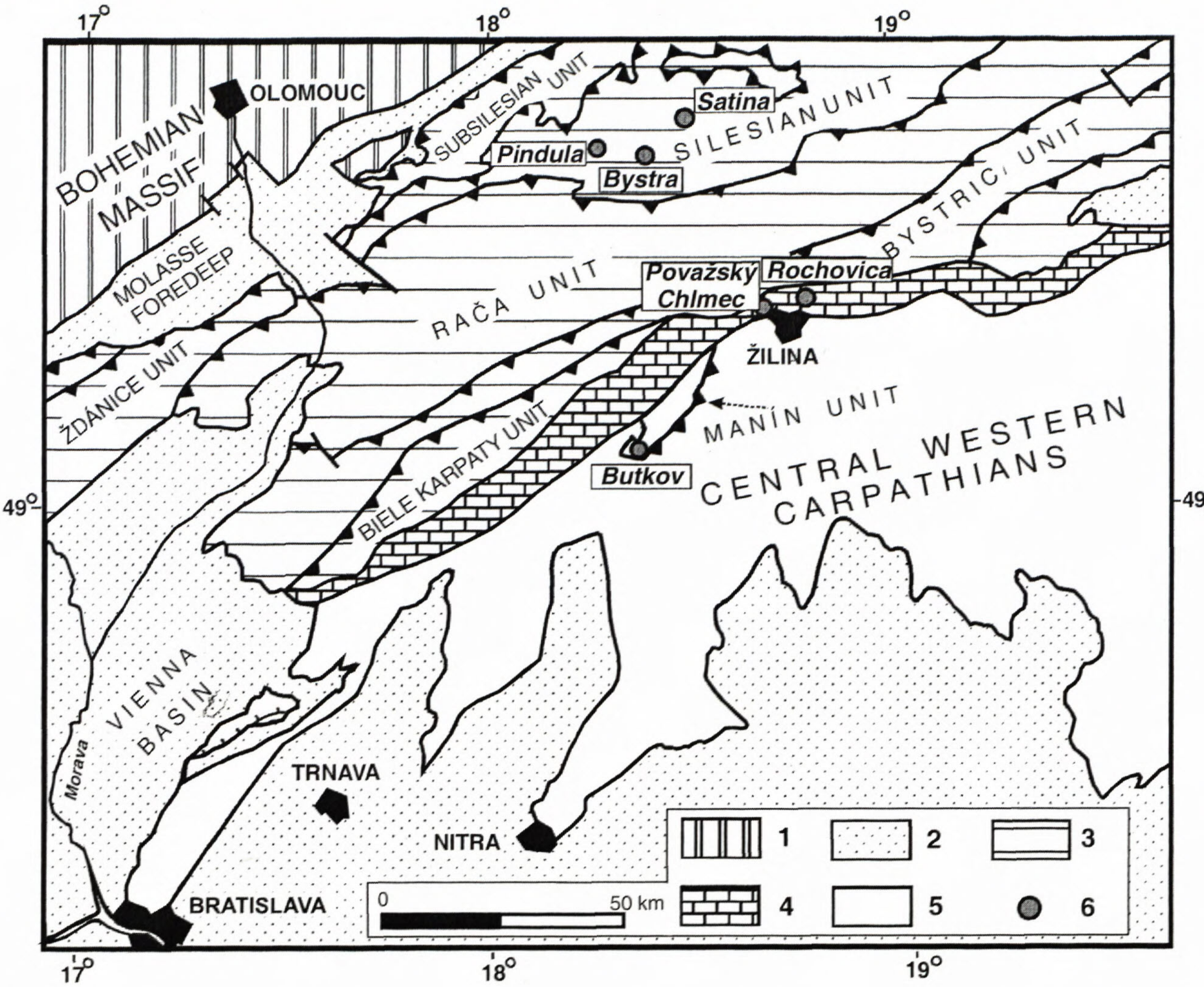

Fig. 1. Principal tectonic units of the Western Carpathians (after Vašíček et al., 1994) and localization of the sections studied. 1 – Bohemian Massif, 2 – Neogene cover, 3 – Outer Western Carpathians, 4 – Pieniny Klippen Belt, 5 – Central Western Carpathians, 6 – locality.

1999, Skupien & Vašíček, 2003), Pindula, located south of the town Frenštát pod Radhoštěm (Skupien, 1997, 1999) and Komorní Lhotka (Skupien, 1998, 1999).

The Pieniny Klippen Belt (PKB) is tectonically the most complicated part of the Western Carpathians. The Upper Aptian – the Lower Albian of the Kysuca Unit (Andrusov & Scheibner, 1960) is represented by spotted limestones with intercalations of dark and red marls (Brodno Formation). This formation is covered by red pelagic marls of the Upper Albian (Rudina Formation).

Attention was paid to Rochovica section situated near Žilina (Fig. 1, Michalík et al, 1999, Skupien, 2003 etc.).

The second section is exposed near Považský Chlmec (Andrusov & Kuthan, 1944, Marschalko, 1986, Vašíček & Rakús, 1993, Skupien et al., 2003). The section comprise Upper Albian flysch deposites of the Klape Unit. The Klape Unit = Periklippen belt (Salaj, 1995) was incorporated in the Pieniny Klippen Belt by the Sarian folding. The pelites contain ammonites of the *Mortoniceras inflatum* ammonite Zone, *Dipoloceras cristatum* Subzone in the quarry and *Hysteroceras orbignyi* Subzone in the river bank.

Manín Unit is regarded, from the paleogeografical point of view, to be either the most external extremity of the Tatric area and/or an independent paleogeographic zone between the Tatric area and the Klippen Belt (Rakús, 1977) or a consistuent of the Fatric nappe system (Maheľ, 1978, Michalík and Vašíček, 1987). Lower Albian is represented by the pale gray massive organodetritic limestones of „Urgonian" carbonate platform (Podhorie Formation). These are terminated by a hardground, which is overlain by monotonous complex of pelagic dark blue-grey spotted marlstones with thin fine-grained sandstone intercalations. This part repsented Butkov Formation. The marls contain a rich association of nannofossils and planktonic foraminifers indicating the upper part of the Middle Albian to the lower part of the Middle Cenomanian (Gašpariková & Salaj, 1984, Michalík et al., 1990, Boorová & Salaj, 1992).

This sequences are uncovered in the active quarry Butkov by the village Ladce. In the nineties of last century, the section was processed in detail in Vašíček and Michalík (1986), Borza et al. (1987), Boorová and Salaj, 1992, etc. The preliminary palynological result was presented by Skupien et al. (2003).

Methods

Palynological preparations were obtained using a standard procedure involving mineral acid treatment (38% HCl to remove the calcareous fraction, 40% HF to remove silicates). The residue was sieved in ultrasonic apparatus using a 15 μm sieve. Heavy liquid separation was used, when necessary, to remove remaining mineral components. No oxidation was required. Permanent mounts were made in glycerine jelly. Within the scope of the present study the palynological assemblages will be only qualitatively discussed pertaining to their biostratigraphic significance. The dinocyst taxonomy follows Lentin and Williams (1998). All materials are stored at the Institute of Geological Engineering, VŠB-Technical University of Ostrava (Czech Republic).

Stratigraphic evaluation

Silesian Unit

Pelitic sediments of Albian age studied in several localities of the Silesian Unit provided rich dinoflagellate assemblages (see Skupien, 1997, 1999, Skupien & Vašíček, 2003). In addition, in some parts representatives of acritarchs were determined successfully. Results achieved are summarised in Table 1. The stratigraphical division is based on the content of stratigraphically significant dinoflagellates.

At the Aptian/Albian boundary, representatives of *Hystrichosphaerina schindewolfii, Oligosphaeridium verrucosum* and *Surculosphaeridium trunculum* occur in the Silesian Unit for the last time. Simultaneously, *Achomosphaera triangulata, Ovoidinium scabrosum* and *Stephodinium coronatum* appear. Their presence is known already from the latest Aptian (e. g. Davey & Verdier, 1974, Verdier, 1974).

The beginning of the Albian is dated in virtue of the first occurrence of the species *Florentinia stellata* and *Hystrichostrongylon membraniphorum* (Skupien, 1997, 1999). *Florentinia stellata* is index species of the beginning of the Albian (Davey & Verdier, 1971). Together with the above-mentioned species merely the species *Subtilisphaera senegalensis* was found in the Lower Albian. The upper boundary of the Lower Albian may be correlated with the last occurrence of *Muderongia pariata* (e. g. Prössl, 1990). The whole interval from the uppermost Aptian to the Lower Albian is characterised by the dominance of the species *Oligosphaeridium complex*; the species *Oligosphaeridium perforatum* being the characteristic element. In the Lower Albian, *Cerbia tabulata* still occurs frequently. Consequently, one cannot say that its last occurrence is confined to the lowermost Albian as stated by Leereveld (1995).

In the Middle Albian determined according to dinoflagellates, primarily *Carpodinium granulatum, Litosphaeridium conispinum, Surculosphaeridium? longifurcatum* and *Xiphophoridium alatum* appear in the Silesian Unit. The index species for the determination of the beginning of the Middle Albian is *Surculosphaeridium? longifurcatum* that is only known from the Lower/Middle Albian boundary (Davey & Verdier, 1971, Verdier, 1974). What is characteristic is the abundant occurrence of representatives of the genus *Florentinia* (*F. cooksoniae, F. laciniata, F. mantellii, F. radiculata*) and the presence of the species *Atopodinium perforatum*. In its uppermost part, *Protoellipsodinium clavulum* appears for the last time.

In the Upper Albian, the lower part (Inflatum ammonite Zone) may be identified on the basis of the first occurrence of *Atopodinium mirabile, Litosphaeridium siphoniphorum* and *Pervosphaeridium truncatum* (Verdier, 1974, Leereveld, 1995). Simultaneously, the species *Pervosphaeridium pseudhystrichodinium* was observed in the assemblages of the Silesian Unit for the first time.

Table 1. Range chart of the Albian acritarchs and dinoflagellates in the Silesian Unit.

Stratigraphy	pre-Albian	Albian									post Albian
Taxa		Lower			Middle			Upper			
									Vrac.		
1. Cerbia tabulata	■		■								
2. Muderongia pariata	■	■	■	■							
3. Occisucysta duxburyi	■	■	■	■							
4. Systematophora complicata	■	■	■	■							
5. Florentinia radiculata	■	■	■	■	■						
6. Pseudoceratium polymorphum	■	■	■	■	■						
7. Systematophora cretacea	■	■	■	■	■						
8. Gonyaulacysta cretacea	■					■					
9. Hystrichosphaerina schindewolfii	■						?				
10. Batioladinium jaegeri	■				■	■	■				
11. Protoellipsodinium clavulum	■	■	■	■	■	■	■				
12. Dissiliodinium globolus	■	■	■	■	■	■	■	■			
13. Prolixosphaeridium parvispinum	■	■	■	■	■	■	■	■			
14. Achomosphaera neptunii	■	■	■	■	■	■	■	■	■		
15. Circulodinium distinctum	■	■	■	■	■	■	■	■	■		
16. Cribroperidinium edvardsii	■	■	■	■	■	■	■	■	■		
17. Cyclonephelium intonsum	■	■	■	■					■		
18. Oligosphaeridium perforatum colum	■	■	■	■	■	■	■	■	■		
19. Palaeoperidinium cretaceum	■	■	■	■	■	■	■	■	■		
20. Tanyosphaeridium boletus	■	■	■	■	■	■	■	■	■		
21. Fromea amphora	■	■	■	■	■	■	■	■	■	■	
22. Heterosphaeridium heteracanthum	■									■	
23. Hystrichodinium voigtii	■	■	■	■	■	■	■	■	■	■	
24. Kleithriasphaeridium corrugatum	■							■	■	■	
25. Muderongia neocomica	■									■	
26. Muderongia tabulata	■									■	
27. Oligosphaeridium poculum	■								■	■	
28. Protoellipsodinium spinosum	■	■	■	■	■	■	■	■	■	■	
29. Stephodinium spinulosum	■	■							■	■	
30. Achomosphaera ramulifera	■	■	■	■	■	■	■	■	■	■	■
31. Achomosphaera triangulata	■	■	■	■	■	■	■	■	■	■	■
32. Callaiosphaeridium asymmetricum	■	■	■	■	■	■	■	■	■	■	■
33. Cometodinium? whitei	■	■	■	■	■	■	■	■	■	■	■
34. Coronifera oceanica	■	■	■	■	■	■	■	■	■	■	■
35. Cribroperidinium orthoceras	■	■	■	■	■	■	■	■	■	■	■
36. Dapsilidinium multispinosum	■	■	■	■	■	■	■	■	■	■	■
37. Dinopterygium tuberculatum	■							■	■	■	■
38. Endoscrinium campanula	■	■	■	■	■	■	■	■	■	■	■
39. Exochosphaeridium muelleri	■	■	■	■	■	■	■	■	■	■	■
40. Florentinia cooksoniae	■	■	■	■	■	■	■	■	■	■	■
41. Florentinia laciniata	■	■	■	■	■	■	■	■	■	■	■
42. Florentinia mantellii	■	■	■	■	■	■	■	■	■	■	■
43. Hystrichodinium pulchrum	■	■	■	■	■	■	■	■	■	■	■
44. Kiokansium polypes	■	■	■	■	■	■	■	■	■	■	■
45. Kleithriasphaeridium eoinodes	■	■	■	■	■	■	■	■	■	■	■
46. Odontochitina operculata	■	■	■	■	■	■	■	■	■	■	■
47. Oligosphaeridium asterigerum	■	■	■	■	■	■	■	■	■	■	■
48. Oligosphaeridium complex	■	■	■	■	■	■	■	■	■	■	■
49. Oligosphaeridium prolixispinosum	■	■	■	■	■	■	■	■	■	■	■
50. Oligosphaeridium pulcherrimum	■	■	■	■	■	■	■			?	?
51. Ovoidinium scabrosum	■	■	■	■	■	■	■	■	■	■	■
52. Pterodinium cingulatum cingulatum	■	■	■	■	■	■	■	■	■	■	■
53. Spiniferites ramosus	■	■	■	■	■	■	■	■	■	■	■
54. Spiniferites ramosus reticulatus	■	■	■	■	■	■	■	■	■	■	■
55. Stephodinium coronatum	■	■	■	■	■	■	■	■	■	■	■
56. Subtilisphaera perlucida	■	■	■	■	■	■	■	■	■	■	■
57. Wallodinium krutzschii	■	■	■	■	■	■	■	■	■	■	■
58. Wallodinium luna	■	■	■	■	■	■	■	■	■	■	■
59. Subtilisphaera senegalensis		■									
60. Hystrichostrongylon membraniphorum		■	■	■	■	■	■	■	■	■	
61. Florentinia stellata		■	■	■	■	■	■	■	■	■	■
62. Tubulospina oblongata			■								
63. Spiniferites alatus			■						■		

Table 1 – continued

Stratigraphy / Taxa	pre-Albian	Albian – Lower			Albian – Middle			Albian – Upper	Upper – Vrac.		post Albian
64. Cleistosphaeridium clavulum			■								■
65. Cyclonephelium brevispinatum				■							
66. Cyclonephelium maugaad				■							
67. Florentinia resex				■							
68. Muderongia tetracatha				■							
69. Subtilisphaera scabrata				■							
70. Subtilisphaera zawia				■							
71. Subtilisphaera sp.				■							
72. Valensiella reticulata				■							
73. Atopodinium perforatum					■	■					
74. Leberidocysta chlamydata					■	■	■	■	■	■	■
75. Surculosphaeridium? longifurcatum					■	■	■	■	■	■	■
76. Xiphophoridium alatum					■	■	■	■	■	■	■
77. Hystrichosphaeridium arborispinum						■					
78. Carpodinium granulatum						■	■	■	■		
79. Gonyaulacysta cassidata						■	■	■	■		
80. Cyclonephelium compactum						■					■
81. Hystrichosphaeridium recurvatum						■	■	■	■	■	■
82. Rottnestia borussica							■				
83. Litosphaeridium conispinum							■	■	■	■	
84. Surculosphaeridium ? cassospinum							■	■	■	■	
85. Tanyosphaeridium variecalamus							■	■	■	■	■
86. Apteodinium maculatum grande								■			
87. Vesperopsis digitata								■			
88. Atopodinium mirabile								■	■		
89. Spiniferites ancoriferus ghiran								■	■		
90. Cyclonephelium membraniphorum								■	■	■	■
91. Hystrichosphaeridium bowerbankii								■	■	■	■
92. Litosphaeridium siphoniphorum								■	■	■	■
93. Pervosphaeridium pseudhystrichodinium								■	■	■	■
94. Pervosphaeridium truncatum								■	■	■	■
95. Micrhystridium inconspicuum									■		
96. Spiniferites scabrosus									■		
97. Surculosphaeridium ? basifurcatum									■		
98. Endoceratium dettmanniae									■	■	
99. Hapsocysta peridictya									■	■	
100. Protoellipsodinium spinocristatum									■	■	
101. Spiniferites ancoriferus									■	■	
102. Subtilisphaera cheit									■	■	
103. Achomosphaera verdieri									■	■	■
104. Disphaeria munda									■	■	■
105. Exochosphaeridium phragmites									■	■	■
106. Ovoidinium verrucosum									■	■	■
107. Palaeohystrichophora infusorioides									■	■	■
108. Protoellipsodinium cf. seghire										■	
109. Pterodinium cingulatum reticulatum										■	
110. Surculosphaeridium cf. belowii										■	■
111. Xenascus ceratioides										■	■

The higher part of the Upper Albian (Vraconian – Dispar ammonite Zone) is characterised by the first occurrence of the species *Endoceratium dettmaniae* and *Palaeohystrichophora infusorioides* (Tocher & Jarvis, 1996). In the higher part, *Xenascus ceratoides* appears for the first time. The abundant representation of the genus *Ovoidinium* (*O. scabrosum, O. verrucosum*) and the species *Achomosphaera triangulata* is a characteristic feature.

The first joint occurrences of the species *Ovoidinium scabrosum* and *Ovoidinium verrucosum* are known from the uppermost Albian, namely from the Dispar ammonite zone (e. g. Foucher, 1981, Tocher & Jarvis, 1994, and others). At the same time, any occurrence of representatives of *Ovoidinium scabrosum* and *Protoellipsodinium spinocristatum* is not known from sediments younger than the uppermost Albian.

In the uppermost part of the Albian, a proportion of species *Litosphaeridium siphoniphorum* and *Palaeohystrichophora infusorioides* grows markedly. It is the occurrence of the species *Hapsocysta peridictya* appearing in the uppermost Albian of the Silesian Unit for the first time that is of interest. It is already known from the Upper Barremian in other parts of the Western Carpathians (Skupien, et al., 2003).

The Albian/Cenomanian boundary is indicated by the last occurrence of *Litosphaeridium conispinum* and the first occurrence of *Exochosphaeridium bifidum* in the locality of Bystrá (Skupien & Vašíček, 2003). In the Lower Cenomanian, *Odontochitina costata* appears for the first time; representatives of the species *Achomosphaera triangulata, Dinopterygium cladoides, D. tuberculatum* and *Pervosphaeridium pseudhystrichodinium* are abundant.

The Pieniny Klippen Belt

The Košer Albion is well determined by the planktonic foraminifers too (Salaj, 1995). Here are the well preserved dinoflagellate assemblages (Tab. 2). The beginning of the Lower Albian was concluded on the basis of the appearance of the *Xiphophoridium alatum* and *Pervosphaeridium pseudhystrichodinium* on the Rochovica section (Skupien, 2003). *Xiphophoridium alatum* is mostly regarded an Albian species; e. g. Monteil (in Stover et al., 1996) described it from the Upper Albian. Prössl (1990) reported it from the Middle Albian, but it also appeared in the uppermost Aptian in SE France (Vink, 1995). The Lower Albian dinoflagellate associations are characterized by the dominance of *Achomosphaera ramulifera, Pervosphaeridium pseudhystrichodinium* and *Spiniferites ramosus.*

Higher, the assemblages change significantly by enrichment in species *Adnatosphaeridium tutulosum, Hapsocysta dictiota, Litosphaeridium arundum, Litosphaeridium conispinum, Surculosphaeridium? longifurcatum* and other species representing a part of typical Albian dinoflagellate assemblages. *Litosphaeridium arundum*, the first occurrence of which has been generally reported from the Lower Albian, is the stratigraphically most significant. However, according to Verdier (1974), for example, *Surculosphaeridium? longifurcatum* appeared in the Middle Albian for the first time. This would correspond to the data of Prössl (1990) who described the occurrence of *L. arundum* in the uppermost part of the Lower Albian to the lowermost part of the Upper Albian. It is possible delimited the Middle Albian. *Achomosphaera ramulifera, Exochosphaeridium muelleri, Odontochitina operculata* and *Pterodinium cingulatum* are dominant.

Ammonite Inflatum Zone was determined in the Upper Albian (Skupien, 2003) on the basis of occurence of species *Litosphaeridium siphoniphorum* together with *Gardodinium trabeculosum, Hapsocysta peridictya, Litosphaeridium conispinum* and *Pervosphaeridium pseudohystrichodinium.* The first occurrence of *Litosphaeridium siphoniphorum* was confirmed to the Upper Albian ammonite Inflatum Zone. Simultaneously, the sample contains *Gardodinium trabeculosum*, the last occurrence of which has been reported from SE France from the Lower Albian (Van Erve et al., 1980, Leereveld, 1995), but Monteil (in Stover et al., 1996) described it from the lower part of the Upper Albian. No species characteristic of the higher part of the Upper Albian have been found in the Pieniny Klippen Belt. *Achomosphaera ramulifera, Hapsocysta peridictya, Litosphaeridium siphoniphorum* and *Pervosphaeridium pseudhystrichodinium* predominate.

Table 2. Range chart of the Albian acritarchs and dinoflagellates in the Pieniny Klippen Belt.

Stratigraphy / Taxa	pre-Albian	Albian: Lower	Albian: Middle	Albian: Upper
1. Apteodinium granulatum				
2. Callaiosphaeridium asymmetricum				
3. Callaiosphaeridium trycherium				
4. Hystrichosphaerina schindewolfii				
5. Muderongia cf. staurota				
6. Circulodinium brevispinosum				
7. Cribroperdinum sp.				
8. Florentinia cooksoniae				
9. Gonyaulacysta cretacea				
10. Wallodinium krutzschii				
11. Prolixosphaeridium parvispinum				
12. Achomosphaera verdieri				
13. Circulodinium vermiculatum				
14. Tehamadinium sp.				
15. Endoscrinium campanula				
16. Kiokansium polypes				
17. Spiniferites ramosus				
18. Oligosphaeridium poculum				
19. Achomosphaera ramulifera				
20. Achomosphaera triangulata				
21. Cometodinium? whitei				
22. Coronifera oceanica				
23. Dapsilidinium multispinosum				
24. Exochosphaeridium muelleri				
25. Florentinia mantellii				
26. Hapsocysta peridictya				
27. Kleithriasphaeridium eoinodes				
28. Odontochitina operculata				
29. Oligosphaeridium asterigerum				
30. Oligosphaeridium complex				
31. Palaeoperidinium cretaceum				
32. Protoellipsodinium spinosum				
33. Pterodinium cingulatum				
34. Spiniferites sp.				
35. Dapsilidinium duma				
36. Oligosphaeridium pulcherrimum				
37. Pervosphaeridium pseudhystrichodinium				
38. Xiphophoridium alatum				
39. Hapsocysta dictiota				
40. Litosphaeridium arundum				
41. Pseudoceratium polymorphum				
42. Surculosphaeridium? longifurcatum				
43. Stephodinium coronatum				
44. Adnatosphaeridium tutulosum				
45. Litosphaeridium conispinum				
46. Florentinia stellata				
47. Hystrichostrongylon membraniphorum				
48. Dingodinium albertii				
49. Protoellipsodinium seghire				
50. Tanyosphaeridium sp.				
51. Muderongia sp.				
52. Codoniella campanulata				
53. Gardodinium trabeculosum				
54. Leberidocysta sp.				
55. Hystrichosphaeridium bowerbankii				
56. Litosphaeridium siphoniphorum				
57. Cleistosphaeridium multispinosum				
58. Codoniella psygma				
59. Leberidocysta chlamydata				
60. Ovoidinium sp.				
61. Pervosphaeridium sp.				
62. Trabeculidinium quiquetrum				
63. Xenascus sp.				

Table 3. Range chart of the Albian acritarchs and dinoflagellates in the Manín Unit

Stratigraphy / Ammonite Zones / Taxa	pre-Albian	Upper Albian: Inflatum	Upper Albian: Dispar
1. Dapsilidinium multispinosum			
2. Hystrichodinium voigtii			
3. Protoellipsodinium spinosum			
4. Circulodinium distinctum			
5. Coronifera oceanica			
6. Exochosphaeridium muelleri			
7. Kiokansium polypes			
8. Spiniferites sp.			
9. Achomosphaera triangulata			
10. Cometodinium? whitei			
11. Cribroperidinium sp.			
12. Endoscrinium campanula			
13. Hystrichodinium pulchrum			
14. Kleithriasphaeridium eoinodes			
15. Oligosphaeridium complex			
16. Spiniferites ramosus			
17. Wallodinium krutzschii			
18. Pterodinium cingulatum			
19. Dinopterygium cladoides			
20. Florentinia cooksoniae			
21. Cauca parva			
22. Hystrichosphaeridium bowerbankii			
23. Cleistosphaeridium clavulum			
24. Litosphaeridium siphoniphorum			
25. Odontochitina operculata			
26. Pervosphaeridium truncatum			
27. Pervosphaeridium pseudhystrichodininum			
28. Pterodinium cingulatum reticulatum			
29. Xiphophoridium alatum			
30. Achomosphaera verdieri			
31. Achomosphaera ramulifera			
32. Cyclonephelium paucispinum			
33. Hystrichostrongylon membraniphorum			
34. Prolixosphaeridium conulum			
35. Spiniferites ramosus reticulatus			
36. Stephodinium coronatum			
37. Adnatosphaeridium tutulosum			
38. Gonyaulacysta extensa			
39. Ovoidinium scabrosum			
40. Leberidocysta chlamydata			
41. Ovoidinium sp.			
42. Endoceratium dettmanniae			
43. Veryhachium sp.			
44. Atopodinium perforatum			
45. Callaiosphaeridium assymmetricum			
46. Ovoidinium verrucosum			
47. Prolixosphaeridium sp.			
48. Tenua hystrix			
49. Kiokansium sp.			

Manín Unit

Albian dinoflagellate cysts were found in the lowermost part of the marlstones (Skupien et al., 2003) of the Upper Albian – Lower Cenomanian Butkov Formation (Boorová & Salaj, 1992). Dinoflagellate cysts dominate (Tab. 3), acritarchs (e. g. *Wallodinium* sp., *Veryhachium* sp.) occur sporadically.

The samples contain stratigraphically significant species of dinoflagellates, such as *Endoceratium dettmanniae, Litosphaeridium siphoniphorum, Ovoidinium verrucosum, Prolixosphaeridium conulum.* The first occurrence of *Litosphaeridium siphoniphorum* was confined to the Upper Albian Inflatum ammonite Zone and the first occurrence of *Prolixosphaeridium conulum* delimits the Dispar ammonite Zone, which is supported by the presence of species *Endoceratium dettmaniae* and *Ovoidinium verrucosum* (Davey & Verdier, 1973, Leereveld, 1995). *Litosphaeridium siphoniphorum, Pervosphaeridium pseudhystrichodinium, Pterodinium cingulatum* and *Xiphophorodium alatum* predominate in the Inflatum Zone. In the higher part (Dispar Zone) dominance of the *Exochosphaeridium muelleri* and *Spiniferites ramosus* increase.

Conclusion

All the studied formations of geological units of the Western Carpathians belonging to the Albian show the abundant representation of dinoflagellates associated

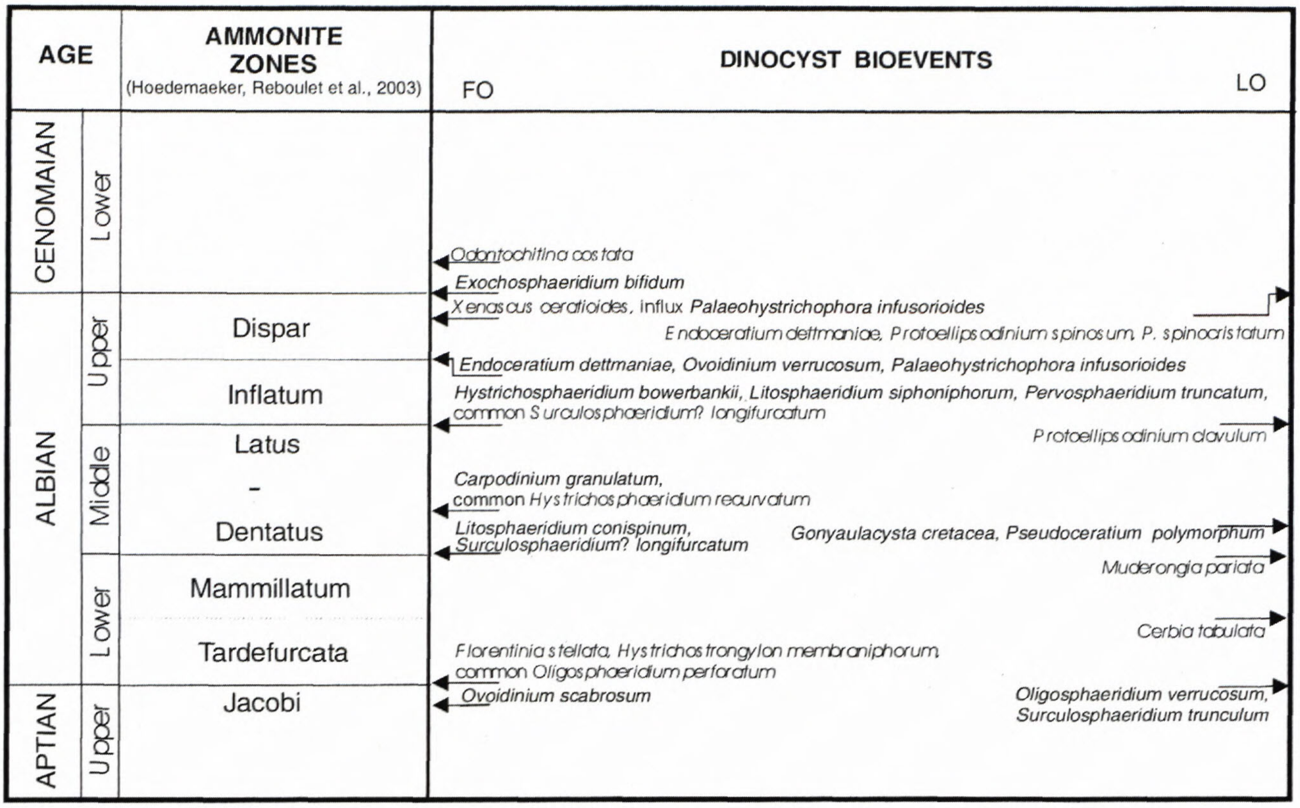

Fig. 2. Albian dinocyst events of the Western Carpathians.

especially with the pelagic members of the sequence of strata. Differences in the amount of the dinoflagellates are given above all by the lithological character of sediments. Occurrence of dinoflagellates is documented best in the Silesian Unit being characterised by the deepwater sedimentation of slightly calcareous pelites. On the other hand, Albian grey organodetritic limestones in the Manín Unit are totally unsuitable, and that is why merely a pelitic part of the Late Albian has been found.

At the same time, it is necessary to point out that the pelitic sediments of Albian age in the Western Carpathians do not enable any correlation of the dinoflagellates with ammonite zones, because there is a lack of the macrofauna (with the exception of the Upper Albian in the Považský Chlmec). The goal of this study is to show differences in the assemblages of particular parts of the Western Carpathians as well as possibilities of their biostratigraphical use in this region.

The investigation of vertical distribution of the dinoflagellates in Albian shown qualitative (first – FO and last – LO occurence) changes. The taxa used in the bioevents have been chosen because of their restricted stratigraphic distribution and, where possible, because of their known occurence in Tethyan deposits. The bioevents scheme can be seen in Fig. 2, and are compared with presumptive ammonite zones deduced on the dinocysts content. Significant dinocysts are illustrated in Plates 1 and 2.

The Aptian/Albian boundary can be observed best in the Silesian Unit. The first occurrences of *Hystrichostrongylon membraniphorum* and *Florentinia stellata* may be taken as identification characters. In the Klippen Belt, the first occurrence of *Xiphophoridium alatum* may be considered as well. The last occurrences of *Cerbia tabulata* and *Hystrichosphaerina schindewolfii* in the Lower Albian are interesting. They are generally connected with the Aptian/Albian boundary.

The Middle Albian is documented both in the Silesian Unit and the Klippen Belt. In both the units, its beginning is determined on the base of the first occurrence of *Surculosphaeridium*? *longifurcatum* together with the occurrences of *Litosphaeridium conispinum*. The last occurrence of *Gonyaulacysta cretacea* and *Pseudoceratium polymorphum* in the lower part of the Middle Albian is interesting.

The Upper Albian is documented in all the three units. The assemblages of dinoflagellates do not substantially differ from each other. The beginning of the Late Albian is determined according to the first occurrence of *Litosphaeridium siphoniphorum*. In all the units, *Hystrichosphaeridium bowerbankii* also appears for the first time.

In the higher part of the Upper Albian (from the Dispar ammonite zone), which was only found in the Silesian and the Manín Unit, *Endoceratium dettmaniae, Ovoidinium verrucosum* and *Palaeohystrichophora infusorioides* exist for the first time. The last occurrence of the species *Palaeoperidinium cretaceum* may be important. Moreover, the Silesian Unit is characterised by the last occurrence of *Achomosphaera neptunii* in the Upper Albian, although this is already generally known from the Late Aptian.

The Albian of all the units shows the abundance of *Achomosphaera ramulifera, A. triangulata, Coronifer* *oceanica, Kleithriasphaeridium eoinodes, Odontochitina operculata, Oligosphaeridium complex* and *Xiphophoridium alatum.*

In the Silesian Unit the abundant representatives of the genera *Florentinia* and *Subtilisphaera* are typical. In the Pieniny Klippen Belt, in addition to this, the Albian is characterised by the abundant representatives of the genus *Hapsocysta*.

Many zonations exist concerning the distribution of Albian dinocysts. However, none of them covers the Tethyan area. Most of the published dinocyst zonations for the Lower Cretaceous are sumarized in Stover et al (1996). The concept of a „zonation" is felt to be too rigid for what should be a constantly evolving process of biostratigraphical refinement. Such zonation are only useful at the time of their erection, thereafter the scheme becomes more and more destabilised as new data is added. Instead of a formalised zonation, I have presented the data amassed in the form of an informal series of event, which is capable of being updated at any time in the future.

Acknowledgement

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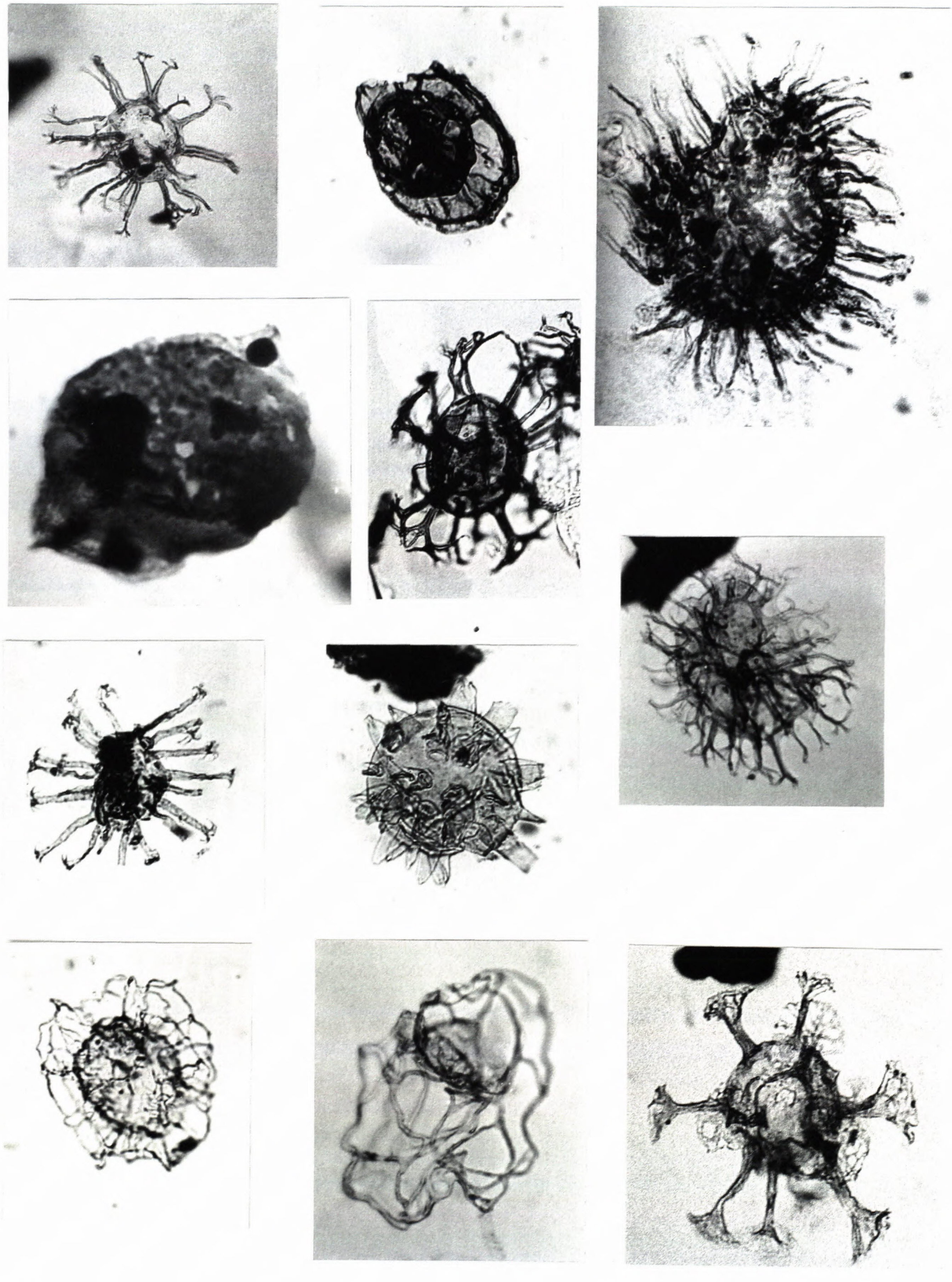
Appendix

An alphabetic index of dinocyst taxa is provided below. Taxonomic citations can be found in Williams et al. (1998). Numbers in parentheses refer to the position of the species in the distribution chart of the Silesian Unit, PKB and Manín Unit (Figs 3, 4 and 5 respectively). A zero indicates that the species is absent from that particular locality. Significan dinocysts are illustrated in Plates 1 and 2.

Dinoflagellates

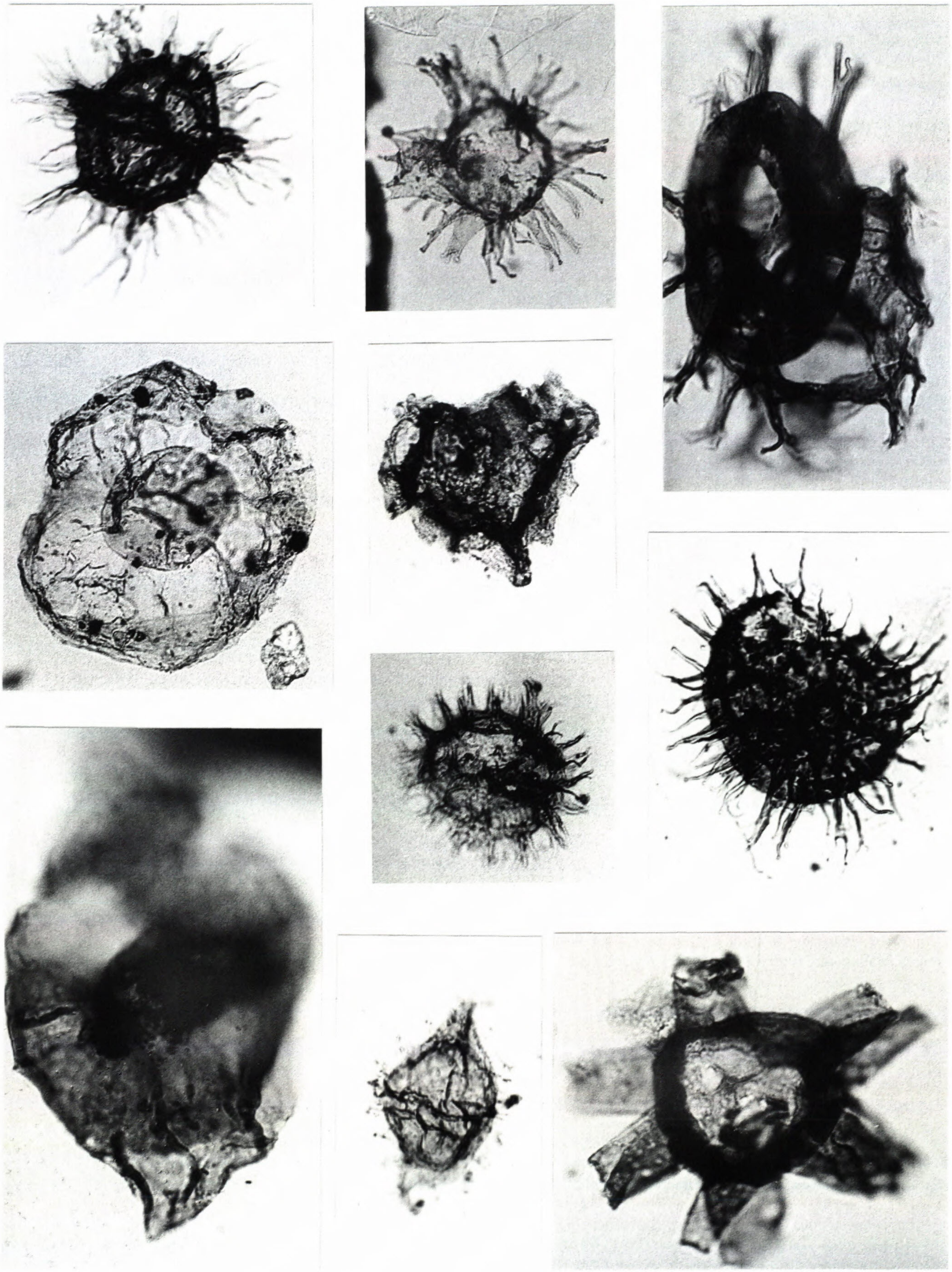
Achomosphaera neptunii (Eisenack, 1958) Davey & Williams, 1966 (14, 0, 0)
Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963 (30, 19, 31)
Achomosphaera triangulata (Gerlach, 1961) Davey & Williams, 1969 (31, 20, 9)
Achomosphaera verdieri Below, 1982 (103, 12, 30)
Adnatosphaeridium tutulosum (Cookson & Eisenack, 1960) Morgan, 1980 (0, 44, 37)
Apteodinium granulatum Eisenack, 1958 (0, 1, 0)
Apteodinium maculatum subsp. *grande* Eisenack & Cookson, 1960 (86, 0, 0)
Atopodinium mirabile (Below, 1984) Masure, 1991 (88, 0, 0)
Atopodinium perforatum (Clarke & Verdier, 1967) Masure, 1991 (73, 0, 44)
Batioladinium jaegeri (Alberti, 1961) Brideaux, 1975 (10, 0, 0)
Callaiosphaeridium asymmetricum (Deflandre & Courteville, 1939) Davey & Williams, 1966 (32, 2, 45)
Callaiosphaeridium trycherium Duxbury, 1980 (0, 3, 0)
Carpodinium granulatum Cookson & Eisenack, 1962 (78, 0, 0)
Cauca parva (Alberti, 1961) Davey & Verdier, 1971 (0, 0, 21)
Cerbia tabulata (Davey & Verdier, 1974), Below, 1981 (1, 0, 0)
Circulodinium brevispinosum (Apocock, 1960) Jansonius, 1986 (0, 6, 0)
Circulodinium distinctum (Deflandre & Cookson, 1955) Jansonius, 1986 (15, 0, 4)
Circulodinium vermiculatum Stover & Helby, 1987 (0, 13, 0)
Cleistosphaeridium clavulum (Davey, 1969) Below, 1982 (64, 0, 23)
Cleistosphaeridium? multispinosum (C. Singh, 1964) Brideaux, 1971 (0, 57, 0)
Codoniella campanulata Cookson & Eisenack, 1961 (0, 52, 0)
Codoniella psygma Davey, 1979 (0, 58, 0)
Cometodinium? whitei (Deflandre & Courteville, 1939) Stover & Evitt, 1978 (33, 21, 10)
Cometodinium sp. (0, 7, 0)
Coronifera oceanica Cookson & Eisenack, 1958 (34, 22, 5)
Cribroperidinium edwardsii (Cookson & Eisenack, 1958) Davey, 1969 (16, 0, 0)
Cribroperidinium orthoceras (Eisenack, 1958) Davey, 1969 (35, 0, 0)
Cribroperidinium sp. (0, 7, 11)
Cyclonephelium brevispinatum (Millioud, 1969) Below, 1981 (65, 0, 0)
Cyclonephelium compactum Deflandre & Cookson, 1955 (80, 0, 0)
Cyclonephelium intonsum Duxbury, 1983 (17, 0, 0)
Cyclonephelium maugaad Below, 1981 (66, 0, 0)
Cyclonephelium membraniphorum Cookson & Eisenack, 1962 (90, 0, 0)
Cyclonephelium paucispinum Davey, 1969 (0, 0, 32)
Dapsilidinium duma (Below, 1982) lentin & Williams, 1985 (0, 35, 0)
Dapsilidinium multispinosum (Davey, 1974) Bujak et al., 1980 (36, 23, 1)
Dingodinium albertii Sarjeant, 1966 (0, 48, 0)
Dinopterygium cladoides Deflandre, 1935 (0, 0, 19)
Dinopterygium tuberculatum (Eisenack & Cookson, 1960) Stover & Evitt, 1978 (37, 0, 0)
Disphaeria munda (Davey & Verdier, 1973) Norvick in Norvick & Burger, 1976 (104, 0, 0)
Dissiliodinium globulus Drugg, 1978 (12, 0, 0)
Endoceratium dettmanniae (Cookson & Hughes, 1964) Stover & Evitt, 1978 (98, 0, 42)
Endoscrinium campanula (Gocht, 1959) Vozzhennikova, 1967 (38, 15, 12)
Exochosphaeridium muelleri Yun, 1981 (39, 24, 6)
Exochosphaeridium phragmites Davey et al., 1966 (105, 0, 0)
Florentinia cooksoniae (C. Singh, 1971) Duxbury, 1980 (40, 8, 20)
Florentinia laciniata Davey & Verdier, 1973 (41, 0, 0)
Florentinia mantellii (Davey & Williams, 1966) Davey & Verdier, 1973 (42, 25, 0)
Florentinia radiculata (Davey & Williams, 1966) Davey & Verdier, 1973 (5, 0, 0)
Florentinia resex Davey & Verdier, 1976 (67, 0, 0)
Florentinia stellata (Maier, 1959) Below, 1982 (61, 46, 0)
Gardodinium trabeculosum (Gocht, 1959) Alberti, 1961 (0, 53, 0)
Gonyaulacysta cassidata (Eisenack & Cookson, 1960) Sarjeant, 1966 (79, 9, 0)
Gonyaulacysta cretacea (Neale & Sarjeant, 1962) Sarjeant, 1969 (8, 9, 0)
Gonyaulacysta extensa Clarke and Verdier, 1967 (0, 0, 38)
Hapsocysta dictyota Davey, 1979 (0, 39, 0)



Hapsocysta peridictya (Eisenack and Cookson, 1960) Davey, 1979 (99, 26, 0)
Heterosphaeridium? *heteracanthum* (Deflandre & Cookson, 1955) Eisenack & Kjellström, 1971 (22, 0, 0)
Hystrichodinium pulchrum Deflandre, 1935 (43, 0, 13)
Hystrichodinium voigtii Alberti, 1961 (23, 0, 2)
Hystrichosphaeridium arborispinum Davey & Williams, 1966 (77, 0, 0)
Hystrichosphaeridium bowerbankii Davey & Williams, 1966 (91, 55, 22)
Hystrichosphaeridium recurvatum (White, 1842) Lejeune-Carpentier, 1940 (81, 0, 0)
Hystrichosphaerina schindewolfii Alberti, 1961 (9, 4, 0)
Hystrichostrongylon membraniphorum Agelopoulos, 1964 (60, 47, 33)
Kiokansium polypes (Tasch, 1964) Stover & Evitt, 1978 (44, 16, 7)
Kiokansium sp. (0, 0, 49)
Kleithriasphaeridium corrugatum Davey, 1974 (24, 0, 0)
Kleithriasphaeridium eoinodes (Eisenack, 1958) Davey, 1974 (45, 27, 14)
Leberidocysta chlamydata Cookson & Eisenack, 1962 (74, 59, 40)
Leberidocysta sp. (0, 54, 0)
Litosphaeridium arundum (Eisenack & Cookson, 1960) Davey, 1979 (0, 40, 0)
Litosphaeridium conispinum Davey & Verdier, 1973 (83, 45, 0)
Litosphaeridium siphoniphorum (Cookson & Eisenack, 1958) Davey & Williams, 1966 (92, 56, 24)
Muderongia neocomica Gocht, 1957 (25, 0, 0)
Muderongia pariata Duxbury, 1983 (2, 0, 0)
Muderongia cf. *staurota* Sarjeant, 1966 (0, 5, 0)
Muderongia tabulata (Raynaud, 1978) Monteil, 1991 (26, 0, 0)
Muderongia tetracatha (Gocht, 1957) Alberti, 1961 (68, 0, 0)
Muderongia sp. (0, 51, 0)
Occisucysta duxburyi Jan du Chęne et al., 1986 (3, 0, 0)
Odontochitina operculata (O. Wetzel, 1933) Deflandre & Cookson, 1955 (46, 28, 25)
Oligosphaeridium? *asterigerum* (Gocht, 1959) Davey & Williams, 1969 (47, 29, 0)
Oligosphaeridium complex (White, 1842) Davey & Williams, 1969 (48, 30, 15)
Oligosphaeridium perforatum subsp. *colum* Duxbury, 1983 (18, 0, 0)
Oligosphaeridium poculum Jain, 1977 (27, 18, 0)
Oligosphaeridium prolixispinosum Davey & Williams, 1966 (49, 0, 0)
Oligosphaeridium pulcherrimum (Deflandre & Cookson, 1955) Davey & Williams, 1966 (50, 36, 0)
Oligosphaeridium sp. (0, 60, 0)
Ovoidinium sp. (0, 0, 3)
Ovoidinium scabrosum (Cookson & Hughes, 1964) Davey, 1970 (51, 0, 39)
Ovoidinium verrucosum (Cookson & Hughes, 1964) Davey, 1970 (106, 0, 46)
Palaeohystrichophora infusorioides Deflandre, 1935 (107, 0, 0)
Palaeoperidinium cretaceum Pocock, 1962 (19, 31, 0)
Pervosphaeridium pseudhystrichodinium (Deflandre, 1937b) Yun, 1981 (93, 37, 27)
Pervosphaeridium truncatum (Davey, 1969) Below, 1982 (94, 0, 26)
Polysphaeridium sp. (0, 61, 0)
Prolixosphaeridium conulum Davey et al. (0, 0, 34)
Prolixosphaeridium parvispinum (Deflandre, 1937) Davey et al. 1969 (13, 11, 0)
Prolixosphaeridium sp. A podle Monteila (1993) (0, 0, 47)
Protoellipsodinium clavulum Davey & Verdier, 1974 (11, 0, 0)
Protoellipsodinium seghire Below, 1981 (0, 49, 0)
Protoellipsodinium cf. *seghire* Below, 1981 (108, 0, 0)
Protoellipsodinium spinosum Davey & Verdier, 1971 (28, 32, 3)
Protoellipsodinium spinocristatum Davey & Verdier, 1971 (100, 0, 0)
Pseudoceratium polymorphum (Eisenack, 1958) Bint, 1986 (6, 41, 0)
Pterodinium cingulatum (O. Wetzel, 1933) Below, 1981 (0, 33, 18)
Pterodinium cingulatum (O. Wetzel, 1933) Below, 1981 subsp. *cingulatum* (52, 0, 0)
Pterodinium cingulatum (O. Wetzel, 1933) Below, 1981 subsp. *reticulatum* Davey & Williams, 1966 (109, 0, 28)
Rottnestia borussica (Eisenack, 1954) Cookson & Eisenack, 1961 (82, 0, 0)
Spiniferites alatus Duxbury, 1977 (63, 0, 0)
Spiniferites ancoriferus Cookson & Eisenack, 1974 (101, 0, 0)
Spiniferites ancoriferus Cookson & Eisenack, 1974 subsp. *ghiran* Below, 1982 (89, 0, 0)
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854 (53, 17, 16)
Spiniferites ramosus subsp. *reticulatus* (Davey & Williams, 1966) Lentin & Williams, 1973 (54, 0, 35)
Spiniferites scabrosus (Wall, 1967) Sarjeant, 1970 (96, 0, 0)
Spiniferites sp. (0, 34, 8)
Stephodinium coronatum Deflandre, 1936 (55, 43, 36)
Stephodinium spinulosum Duxbury, 1983 (29, 0, 0)
Subtilisphaera cheit Below, 1981 (102, 0, 0)
Subtilisphaera perlucida (Alberti, 1959) Jain & Millepied, 1973 (56, 0, 0)
Subtilisphaera scabrata Jain & Millepied, 1973 (69, 0, 0)

Plate 1

1. *Surculosphaeridium*? *longifurcatum* (Firtion, 1952) Davey et al., 1966; diameter 84 μm, Lower Albian, Rochovica section.
2. *Stephodinium coronatum* Deflandre, 1936; length 65 μm, Lower Albian, Pindula section.
3. *Protoellipsodinium spinosum* Davey & Verdier, 1971; length 63 μm, Lower Albian, Pindula section.
4. *Ovoidinium scabrosum* (Cookson & Hughes, 1964) Davey, 1970; length 60 μm, Lower Albian, Pindula section.
5. *Achomosphaera ramulifera* (Deflandre, 1937) Evitt, 1963; length 59 μm, Lower Albian, Pindula section.
6. *Hystrichosphaeridium recurvatum* (White, 1842) Lejeune-Carpentier, 1940; diameter 67 μm, Lower Albian, Pindula section.
7. *Litosphaeridium conispinum* Davey & Verdier, 1973; diameter 52 μm, Lower Albian, Rochovica section.
8. *Achomosphaera triangulata* (Gerlach, 1961) Davey & Williams, 1969; length 81 μm, Lower Albian, Rochovica section.
9. *Adnatosphaeridium tutulosum* (Cookson & Eisenack, 1960) Morgan, 1980; diameter 65 μm, Lower Albian, Rochovica section.
10. *Hapsocysta peridictya* (Eisenack & Cookson, 1960) Davey, 1979; diameter 68 μm, Lower Albian, Rochovica section
11. *Oligosphaeridium perforatum* subsp. *colum* Duxbury, 1983; diameter 90 μm, Middle Albian, Komorní Lhotka.



Subtilisphaera senegalensis Jain & Millepied, 1973 (59, 0, 0)
Subtilisphaera zawia Below, 1981 (70, 0, 0)
Subtilisphaera sp. (71, 0, 0)
Surculosphaeridium? basifurcatum Yun, 1981 (97, 0, 0)
Surculosphaeridium cf. *belowii* Yun, 1981 (110, 0, 0)
Surculosphaeridium? cassospinum Yun, 1981 (84, 0, 0)
Surculosphaeridium? longifurcatum (Firtion, 1952) Davey et al., 1966 (75, 42, 0)
Systematophora complicata (Cookson & Eisenack, 1965) Eisenack, 1969 (4, 0, 0)
Systematophora cretacea Davey, 1979 (7, 0, 0)
Tanyosphaeridium boletus Davey, 1974 (20, 0, 0)
Tanyosphaeridium variecalamus Davey & Williams, 1966 (85, 0, 0)
Tanyosphaeridium sp. (0, 50, 0)
Tehamadinium sp. (0, 14, 0)
Tenua hystrix Eisenack, 1958 (0, 0, 48)
Trabeculidium quinquetrum Duxbury, 1980 (0, 62, 0)
Valensiella reticulata (Davey, 1969) Courtinat, 1989 (72, 0, 0)
?*Vesperopsis digitata* (Duxbury, 1983) Bint, 1986 (87, 0, 0)
Xenascus sp. (0, 63, 0)
Xenascus ceratioides (Deflandre, 1937) Lentin & Williams, 1973 (111, 0, 0)
Xiphophoridium alatum (Cookson & Eisenack, 1962) Sarjeant, 1966 (76, 38, 29)

Acritarchs

Fromea amphora Cookson & Eisenack, 1958 (21, 0, 0)
Micrhystridinium inconspicuum (Deflandre, 1935) Deflandre, 1937 (95, 0, 0)
Tubulospina oblongata Davey,1970 (62, 0, 0)
Veryhachium sp. (0, 0, 43)
Wallodinium krutzschii (Alberti, 1961) Habib, 1972 (57, 10, 17)
Wallodinium luna (Cookson & Eisenack, 1960) Lentin & Williams, 1973 (58, 0, 0)

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Plate 2

1. *Xiphophoridium alatum* (Cookson & Eisenack, 1962) Sarjeant, 1966; length 74 μm, Upper Albian, Butkov quarry.
2. *Florentinia laciniata* Davey & Verdier, 1973; length 70 μm, Upper Albian, Komorní Lhotka.
3. *Hystrichostrogylon membraniphorum* Agelopoulos, 1964; length 65 μm, Middle Albian, Rochovica section.
4. *Disphaeria munda* (Davey & Verdier, 1973) Norvick in Norvick & Burger, 1976; diameter 72 μm, Upper Albian, Komorní Lhotka.
5. *Endoceratium dettmanniae* (Cookson & Hughes, 1964) Stover & Evitt, 1978; width 60 μm, Upper Albian, Komorní Lhotka.
6. *Pervosphaeridium truncatum* (Davey, 1969) Below, 1982; length 59 μm, Upper Albian, Komorní Lhotka.
7. *Pervosphaeridium pseudhystrichodinium* (Deflandre, 1937) Yun, 1981; length 81 μm, Upper Albian, Butkov quarry.
8. *Ovoidinium verrucosum* (Cookson & Hughes, 1964) Davey, 1970; length 66 μm, Upper Albian, Komorní Lhotka.
9. *Palaeohystrichophora infusorioides* Deflandre, 1935; length 60 μm, Upper Albian, Bystrá section.
10. *Litosphaeridium siphoniphorum* (Cookson & Eisenack, 1958) Davey & Williams, 1966; diameter 52 μm, Upper Albian, Rochovica section.

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Wherefore a new Fe carbonate body have not been discovered within the Nižná Slaná region – reasons and consequences for geological structure interpretation

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Abstract: A Nižná Slaná depression creates a western portion of a historical mining region – Spišsko-Gemerské Ore Mts., situated in the Eastern part of the Slovak republic. From the economic geology point of view the most important element of the area are Late Paleozoic black phyllites sequences with occurrence of strata bound ore bodies – Fe carbonates (siderite, ankerite). There is only one deposit exploited up-to-date here – Manó-Gabriela deposit near Nižná Slaná village. A complex of geological works with a main goal – to find new ore body and to increase ore stock of the deposit have been carried out. The selected objects that had been possessed appropriate attributes have been proposed for drilling. In spite of finding out of several very promising places from deposit viewpoint, the results of prospecting point out that it is practically excluded to expect the occurrence of another Fe carbonate ore bodies.

Key words: Spišsko-gemerské Ore Mts., Nižná Slaná region, hidden Fe carbonate bodies prospecting, and a drill hole verification of data interpretation.

Introduction

The Nižná Slaná region has become due to results of geological survey (last 50 years) the most important basis of Fe-ore in the whole area of Western Carpathians. The geological structure of the area is very particularly described in many works – Abonyi et al., 1966, Varga, (1970, 1970a), Ilavský, (1974), Lörincz (1989), Bajaník, et al. (1994), Grecula et al. (1995), etc... and therefore there is neither purpose nor space here to repeat it. (Fig. 1).

We are concentrating only at several important factors substantial for Fe carbonates prospecting.

The basic tectonic structure of the Nižná Slaná region is an asymmetric anticline so called Hnilecká one, or the Volovec anticline (Snopko et al., 1972), with a crest W – E direction (Fig. 2). Its southern limb has shallow inclination against northern one. The core of this is created by the formation of black phyllites with lydites and carbonates – ore bearing horizon. Black phyllites represent footwall of carbonatic bodies. Porphyroids are underlying and overlying the horizon. The whole area belongs to the western part of known belt of carbonates bodies named Hanková village – Volovec hill.

The main portion of ore stock in the area is in the deposit Manó-Gabriela situated in the southern limb of anticline. The deposit has arc-like horizontal shape and its inclination deptward becomes gradually smaller. The thickness of ore bearing formation is to 450 m, the thickness of ore bodies is maximum 70 m, and the directional length reaches value 800 m, and inclined length 350 m. The depth of ore bodies is changed from 100 to 400 m. The main mineral mass is created by siderite and ankerite. Following minerals are quartz, pyrite, arsenopyrite, sphalerite, tetrahedrite, hematite, jamesonite, boulangerite, calcite, etc...From the prospecting point of view are important cinnabar impregnation and native mercury directly in the ore bodies.

From the genetic viewpoint, the stratiform deposits of this type are regarded to be of hydrothermal – metasomatic origin (Hanuš, 1960, Ilavský, 1974), although interpretation of their syngenetic origin has appeared too. (Turan & Turanová, 1993).

The result of gravity anomaly verification – Kobeliarovo deposit – is located in the northern limb of abovementioned anticline. This is the typical blind deposit, covered by layer of overlying porphyroids (30–50 m), the average inclination 30° towards NE, the maximum thickness is almost 50 m, directional range about 500 m (Ščuka, 1983). The quality of ore is similar as the quality of the Manó-Gabriela deposit.

Another important ore bodies (but much more smaller) are situated similarly in the northern limb of the anticline – the outcropping and the abandoned deposits Ignác and Gampeľ (inclination 70 degrees and more towards the North). Position of the all occurrences of Fe carbonates in the area is depicted on the Fig. 7.

Besides of stratiform Fe mineralization vein and stockwork – disseminative Hg mineralization (thin quartz veinlets containing cinnabar, native Hg + pyrite and arsenopyrite) in the area is developed. (Ilavský, 1956, Beňo, 1960, Lörincz, 1993). From prospecting point of view is substantial, that the known deposits of this mineralization (Trojica and Za baňami) are located always in the overlying position of deep-seated Fe carbonate bodies.

A newer idea of geological structure of the deposit area has been given by Grecula (1995). The basic tectonic

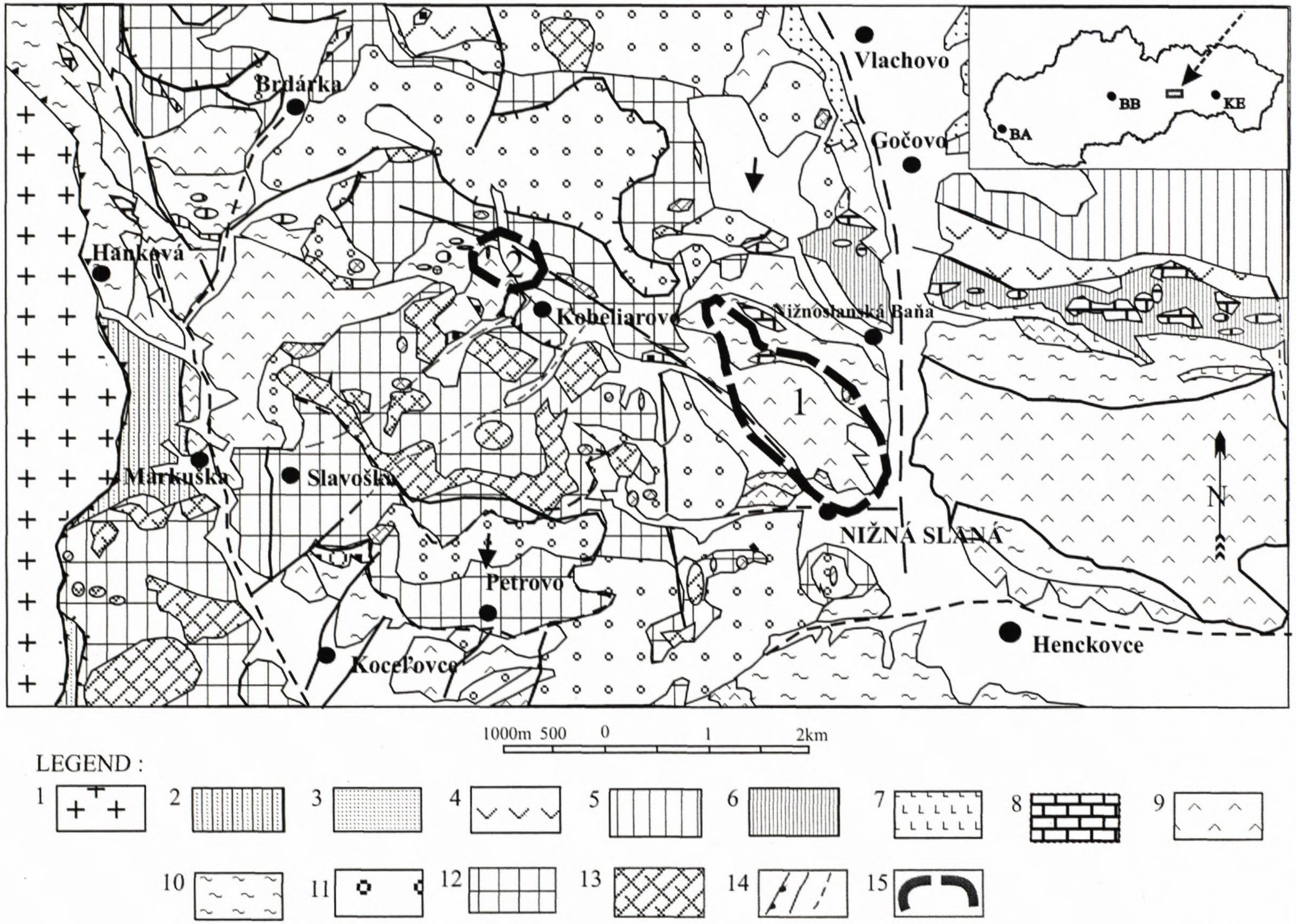

Fig. 1. The geological map of the Nižná Slaná area according to Bajaník et al. (1984), adopted by Kucharič, 2002

VEPORICUM UNIT: *1 – crystalline complexes mostly, 2 –* ***Slatvina Formation*** *(sandstones, cyclically alternating phyllite schists);* ***GEMERICUM UNIT: Vlachovo formation:*** *3 – psammitic complexes mostly, 4 – metarhyolite products, 5 – green phyllites mostly, 6 – black phyllites mostly, 7 – lydites, 8 – carbonates ± Fe;* ***Bystrý potok Formation:*** *9 – metarhyolite products, 10 – black phyllites;****PERMIAN – Rožňava Formation:*** *11 – conglomerates and sandstone mostly Bôrka Nappe, 12 – schists facies mostly, 13 – carbonates facies mostly, 14 – younger units, 15 – overthrusts, faults, presumed faults, 16 – approx. projection of deposit bodies outline to the surface: 1) Manó – Gabriela, 2) Kobeliarovo*

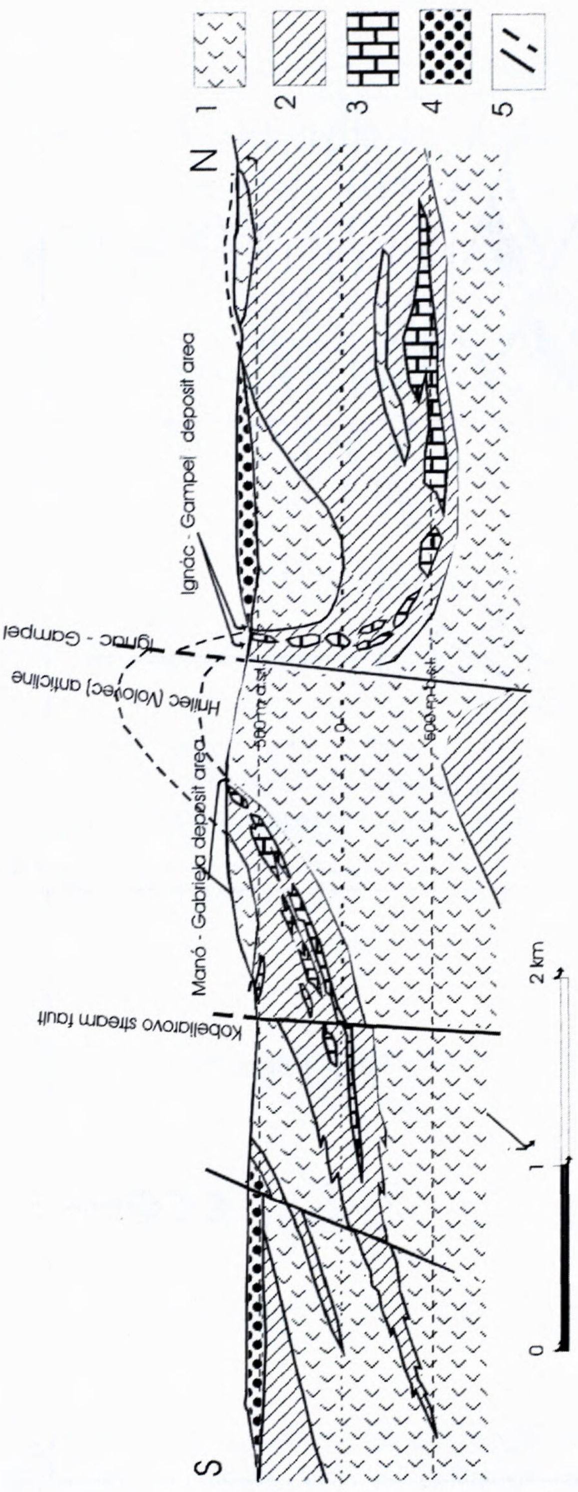

Fig. 2. The geological structure imagination of the area given by Abonyi et al. (1966), adopted by Kucharič, 2002
1 – porphyroids together, 2 – graphitic. – sericitic phyllites complex, 3 – carbonates (± Fe), 4 – younger units, 5 – faults

structure of ore field is the asymmetric anticline again, but its northern limb is strongly reduced and in the depth is recurvated to the South and therefore situated below southern one. Due to is the anticline in the form of incline isoclinal fold interpreted (Fig. 3). Such imagination is derived from the basic interpretation of the whole region of the Spišsko-gemerské Ore Mts., given by above-mentioned author, according to that the region is built by the eight superposed nappes with the direction of overfault to the North (Grecula, 1983).

A structural and mineralogical research was performed in the deposits Ignác, Gampeľ, and Manó. (Sasváry ľet al., 1996.) On the basis of the structural analyses, evaluation of mineralogical and litological relations the deep seated continuation of ore bodies between Ignác and Gampe¾ deposits is expected. Position of interpreted ore bodies would be in the northern limb of the Hnilec anticline, which is formed to the local syncline – minor fold – product of additional tectonic process (Fig. 4).

A philosophy of research

The main portion of geological works has been performed within framework of the project Lörincz et al. (1994). This research complex consisted of geological, geochemical, and geophysical methods as well as drilling works. (An additional geological mapping, geochemistry analyses, mercury content determination in soils, gravimetry, resistivity and induced polarisation profiling and vertical electrical sounding).

From previous knowledge of the area was obvious, that the problem concerns hidden Fe carbonate ore bodies and therefore the most relevant information have been expected from the results of geophysical methods. Regardless of two different opinions at the geological structure of the area itself and at the whole territory of the Spišsko-Gemerské Ore Mts. (Bajaník, 1984, against Grecula, 1983) that has been partly united only by location of the position carbonate bodies in the black phyllites formation (Betliar formation) it was inevitable to find suitable physical „deposit" feature.

Because of two deposits of Fe carbonate had been a direct reflect in the gravity field (positive anomalies) and there were accompanied by the high anomalies of Hg concentration in a back of ore (Manó-Gabriela and Kobeliarovo), the prospecting has been concentrated upon finding and the explanation of similar measured anomalies in the adjoining area. The selected objects that had been possessed such attributes have been proposed for drilling activity – the best verification of geological and geophysical data interpretation.

A leadership among research methods belongs to gravity due to the positive picture of known ore bodies (Manó-Gabriela and discovering of Kobeliarovo deposit) in the gravity field – where anomalies reached almost +2 mGal. (Kotásek, Popelář, 1963).

The interconnection between ore bodies, ore bearing beds and mercury concentration has been known and proved in the previous works (Kucharič and Hojnoš, 1989, Grecula and Kucharič et al., 1992, Háber et al., 1993). This connection is visible from the extension of remarkable regional anomaly of mercury that has been detected in the space of the area in question (Fig. 7). This anomaly seemed to be the largest or probably one of the highest natural one of mercury element in the Western Carpathians region. (Maximum value has been occurred to the West of Kobeliarovo village almost 300 ppm.).

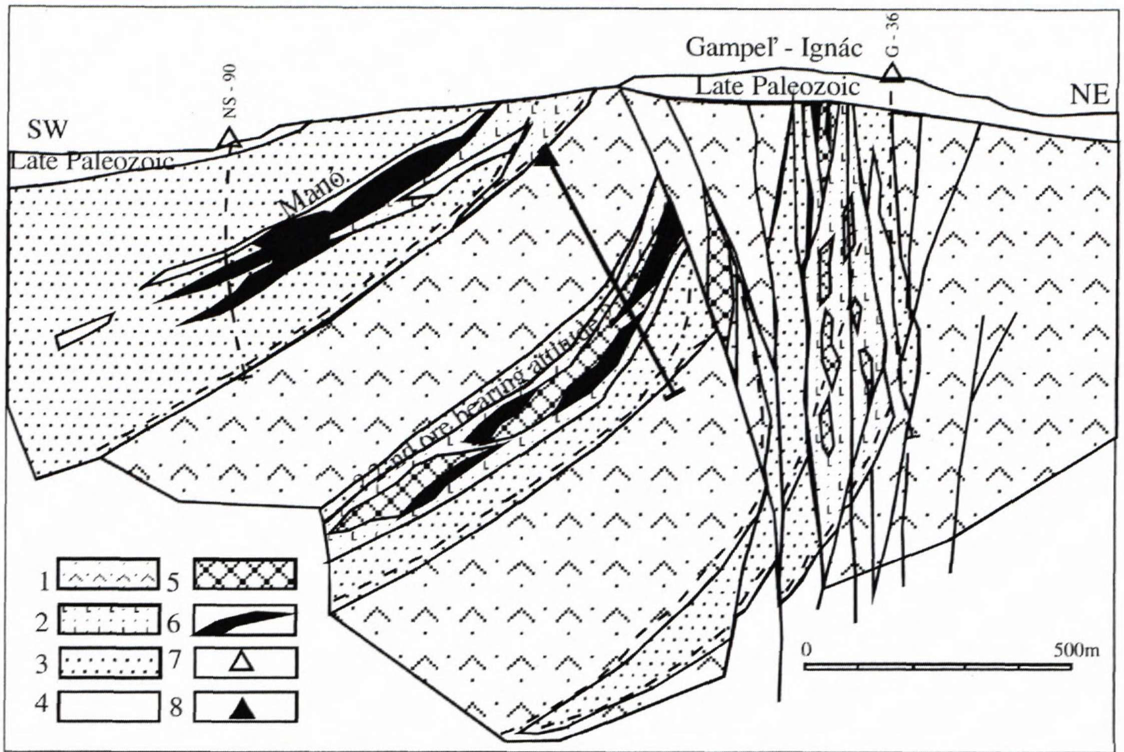

Fig. 3 Imagination of geological structure of the area by Grecula (1994)
1 – porphyroid, 2 – black phyllite with lydites, 3 – ceritic phyllite, 4 – limestone, 5 – ankerite, 6 – ciderite, 7 – previous boreholes, 8 – the projected underground borehole

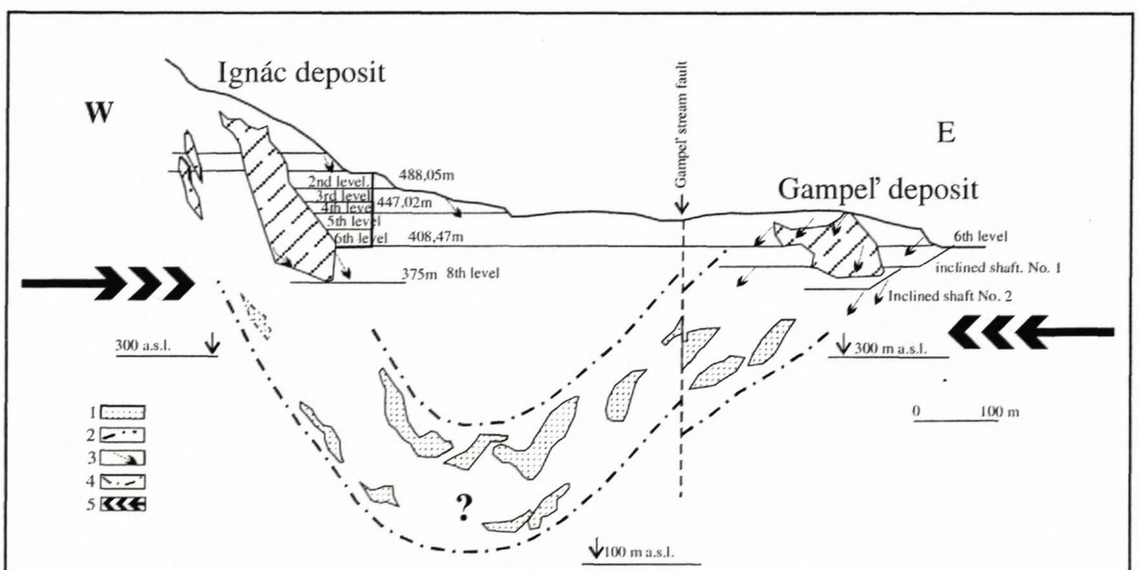

Fig. 4. The interpreted syncline Ignác – Gampeľ by Sasvári et al. (1996), adopted by Kucharič, 2002
1 – the interpreted siderite and ankerite bodies, 2 – the interpreted syncline of productive horizon, 3 – the dook of foliation S1, 4 – robbed space, 5 – the direction of side pressure (?)

According to above mentioned geological works in the ore field is obvious, that the Fe-carbonates horizon is situated in the surroundings of black phyllites environment what does mean conductive medium from geoelectrical point of view. Beside of this, the carbonates itself are non conductive material and therefore in the suitable condition is reasonable to expect their reflect in the resistivity field.

On the basis above-mentioned result the gravity method and the assessment of mercury content in the soils as direct prospecting symptoms can be considered.

In a favourable situation (a sufficient contrast between conductive ore bearing beds – black phyllites – and less, or non conductive carbonates, as well as remarkable geometry of carbonate body) the apparent resistity can be added to these symptoms.

The detection of ore bearing beds itself (which are not only conductive, but also polarizable) using methods of apparent resistivity – (profiling and vertical electrical sounding) and induced polarization in our imagination represents an indirect prospecting symptom.

The step of measured points in the gravimetry has been 100 m; all the other methods have been carried out with the step of 20 m.

Verification of the perspective places

In the coarse of the 50 years, several gravity anomalies have been detected in this area, but not all of them have been verified. On the base above mentioned proves, for purpose of the research it has been indisputable the checking all these object is essential apart of various attitudes to geological structure understanding.

The Petrovo area

This locality is situated in the surroundings of similar village in the SW direction of Manó – Gabriela deposit (Fig. 1, 7).

The auspicious data have been obtained from the regional profile No. 87 of the SGR – geofyzika project. (Mikuška, in Grecula and Kucharič et al., 1992). A conformity of these data with a data from the Kobeliarovo deposit obtained is very explicit visible on the Fig. 5. The borehole PE – 1 has been suggested and drilled on the place of the anomaly near Petrovo village. Its position is marked on the Fig.7 and data depicted in the Tab.1.

From the Tab. 1 is clear, that any carbonate body has not been reached. The attitude of graphitic-sericitic phyllites with the small content of lydites on the bottom part of the borehole is probably the representative of ore bearing beds. The reason of gravity anomaly has been quartzites, which are usually as light rocks considered. Similarly, the tuffaceous phyllites do not belong to heavy rocks too. The chemical analyses have not confirmed increased concentration of some heavy metal. From the Hg content point of view the maximum value are concentrated equally in the upper part of the borehole in rocks of Bôrka nappe. The anomalies of the density and higher contents of mercury are not synergistic and were generated by the different rocks set. The mutual combination of geochemical and density parameters caused that the anomalous object has been interpreted as an exhibit of Fe carbonate body. From the technical part of interpretation has been confirmed occurrence of the anomalous objects but the more important part – a practical one was not fulfilled, because expected output has not been achieved. Therefore, the result has to be as an unsuccessful considered.

The Henckovce area

The locality is situated 5 km to the SSE of Manó – Gabriela deposit approximately. A place for the borehole has been selected based on the occurrence of the positive gravity anomaly (+0.5 mGal). Besides of this, the space of the anomaly has exhibited increased concentration of Hg, the presence of black phyllites in the depth (IP) and exactly the same type of V E S curve as was above productive part of Manó-Gabriela deposit detected. These four favourable symptoms was strengthened by geological map information, due to ore bearing beds from the deposit area Manó-Gabriela have a continuation to SE to the locality in question (Bajaník et al. 1984). In spite of these very promising signs, we were preadmonished on possible shadiness and risks of our interpretation. However a necessity to verify of the auspicious object conducted to setting out of the place for the borehole NO – 1 in the extension of the anomaly. (Kucharič et al., 1997).

The borehole No. NSO – 1 has been situated very close to the eastern part of Henckovce village. The results are exhibited in the Tab 2.

The carbonate bodies were not inquired again.

Content of Hg has been in the whole course of the borehole very low; it means that our interpretation was not true. We supposed some possibility – see above-mentioned shadows – but unfortunately, it was confirmed. From the mercury content point of view, in the porphyroids, these porphyroids on the surface developed can assume as the underlying ones. The enrichment of metapsammites about dispersion of pyrrhotine caused the increasing of density the rocks and the gravity effect of the object has been misinterpreted. On the other hand, the interpretation against situation ascertained by the borehole is quite correct but only from the physical viewpoint and therefore its importance is practically inapplicable. The situation is similar as on the area Petrovo, where quartzite (from younger unit) possessed the high volume density too.

The borehole NSO – 2

The borehole has been situated on the base of geological assumptions – likely prolongation of deposit area to the East, though geological map (Bajaník et al., 1982) adverted at changing the direction of the productive horizon to the SE–NW direction. (Fig.1). There was not any positive gravity anomaly in this space and another methods were without promising results. The data obtained from the borehole are as follows: Tab. 3. Data from the borehole No-NSO-2.

The average density of rocks in the borehole was 2.72 g/cm3. The carbonate rocks have not been reached. The complex of graphitic – sericitic. phyllite did not exhibit the accompanying marks of the ore bearing beds – egz. lydites, carbonates. The content of Hg in the care has been very low.

The Manó – Gabriela deposit area

The borehole V – NSO 1P

This borehole has been drilled out of geophysical prepositions, but its peculiarity was in its position on the 6-th horizon of the Manó–Gabriela deposit, as well as its dip. The main task of the borehole has been to verify a

Slovak Geol. Mag., 10, 3 (2004),215 – 226

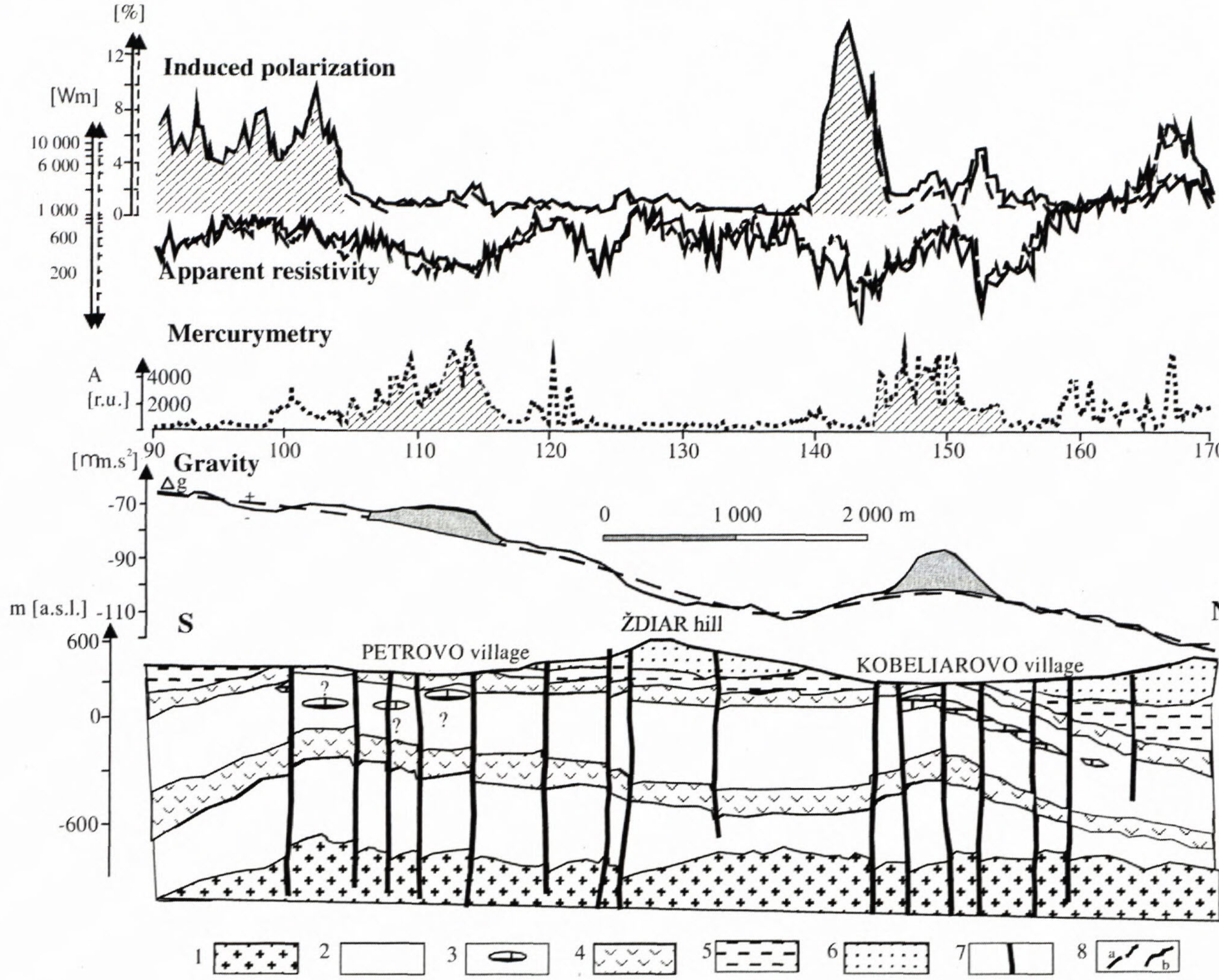

Fig. 5. The showings of ore similarity (Kobeliarovo deposit versa Petrovo perspective area) by Kucharič, 1993
1 – granite, 2 – black phyllite, 3 – Fe carbonate, 4 – porphyroid, 5 – black slate (Late Paleozoic), 6 – younger units together, 7 – fault, 8 – a) gravity regional field, b) gravity residual field

Tab.1. The data from the borehole PE – 1 obtained

The Depth (m)	Lithology	Density (g/cm3)	Content of Hg (ppm)
0 – 27.0	Rauhwacke	2.17	0.76; 0.10; 0.06
27.0 – 48.9	Black schist, tectonic. decomposed	–	5.0; 1.37
48.9 – 57.4	Violet quartzite	2.88	0.17; 0.08
57.4 – 78.0	Tuffaceous phyllite	2.88	0.27;0.39;1.38;0,51
78.0 – 88.1	Conglomerate ± Hg	2.65	2.10;1.54
88.1 – 94.3	Quartzose phyllite	–	0.48
94.3 – 215.5	Porphyroids	Average 2.70	Average 0.27
215.5 – 224.0	Hematitzose phyllite	2.88	0.2
224.0 – 232.8	Tuffaceous phyllite, basic	2.85	0.35
232.8 – 246.7	Porphyroids	–	0.45
246.7 – 450.0	Graphit.-sericitic.phyllites ±lydites	2.77	0.18

geological assumption of nappe structure of the area (Grecula et al., 1995) – see Fig. 3. In the common sense of research, it meant to find out an existence of the northern limb of the above-mentioned anticline (ore bearing formation) but here in the position of inclined isoclinal fold in flat wall of underlying porphyroids. This interpretation supposed occurrences of Fe carbonate bodies here in the northern limb of anticline. The direction of the borehole has been 45 degrees to the North and its length 460.2m. Besides, of attitude of black phyllites in the interval 43.2 – 72.7 m the whole borehole has been drilled in the rock environment of porphyroids. The content of mercury has been steady below level of 1 ppm. According to our knowledge about position and settlement of the

Tab.2. The data from the borehole NSO – 1 obtained

Depth drilled (m)	Depth interpreted (m) (acc. VES)	Lithology
0 – 49.8	0 – 40	debris of porphyroids
49.8 – 102.2	40 – 140	porphyroids
102.2 – 126.7	140 –	seric. phyllites
126.7 – 308.6	– 330	graphitic.-seric. phyllites
308.6 – 503.0	330 –	green porphyroids, compact

Tab.3. The data from the borehole NSO-2 obtained

Depth drilled (m)	Depth interpreted (m) acc. VES	Lithology
0.0 – 6.3	0 – 20 quaternary deposits	quaternary deposits
6.3 – 95.4	20 – 88 porphyroids	porphyroids
94.4 – 142.7	88 – 188 black phyllites	sericitic phyllites
142.7 – 302.1	188 – 255 carbonates ?	black metapsammites with attitudes of black phyllites, veinlets of quartz ± calcite, ankerite
302.1 – 369.6	255 – 400 black phyllites	tuffaceous phyllites
369.6 – 373.0	400 – porphyroids	quartzit.black phyllites

element near deposit and within the deposit itself, it has been obvious, that these porphyroids are really „underlying" ones and therefore occurrence of ore bodies in the depth is excluded. Equally the results of the borehole verified, that the presumption of nappe structure in the area has not been quite correct.

The Kobeliarovo area

Further procedure carrying out and interpretation of geological works set to proving of productive horizon development in this part of the area only, because lack of proper (more distinctive) gravity objects has been obvious. Geological and mining data as well as our geophysical results manifested prolongation of this element to the locality. After analysis of the gravity field was supposed a continuation of attenuated Kobeliarovo anomaly here (The western part). The whole area is created by attitude of porphyroids on the surface of the terrain, which possess abundant concentration of mercury. The average values of this element in the soil cover are 10 – 20 ppm, maximum almost 300 ppm (!) what is item belonging to an ore body (Kucharič et al., 1998). The stockwork – disseminative ore mineralization has been found out by the verification of metasomatic siderite bodies (Lõrincz, 1993). The ore mineralization is developed in the overlay of the Fe-carbonate bodies. It is present in the form of cinnabar disseminations, and quartz veinlets of cm thickness, containing of cinnabar, pyrite, and arsenopyrite, locally disseminated native Hg (Ilavský, 1956, Beňo, 1960). Host rocks are schistose porphyroids. Therefore, these porphyroids (enriched by mercury) as the overlying ones have been considered.

The next borehole NSO-3 (Brdárka–Ježovec) has been situated between old ones Br-6 and Br-10. Both above mentioned boreholes had been perforated Fe carbonates (ankerites), and therefore similar development was expected. This borehole had to be served as guarantee one (Fig. 7.) In spite of assumption, the carbonates were catching in the thickness several cm only. The bottom of the borehole has been in the depth 316 m in the porphyroids environment.

Finally, the boreholes NSO-4 (Brdárka) and NSO-5 (Slavoška) had to verify productive complex below overlying porphyroids. The first one was located on the positive gravity anomaly margin, the second one directly to the shallow gravity maximum. The depth was 348 m, resp. 302.5 m in the porphyroids surroundings only. The abundance of diminutive carbonate veins (ankerite, siderite) was appeared especially in the bottom part of the borehole NSO-4 in the depth 313–320.8 m. The veinlets of siderite (max. 0.5 m thickness) possessed remarkable prospective signs – density 3.56 g/cm3 and mercury concentration 23.6 ppm. It is obvious, that such small objects cannot produce disturbance of gravity field due to small extension and considerable depth. According to RTG analyses, the content of Fe has been 27.7%–30.58 %, Mn 0.925 %–1.081 % and SiO_2 21.94 %– 26.35% and therefore as the breunerite, even mesitite this carbonate can be classified (Turanová, Turan 1989). The similar object in the porphyroids surroundings had been found in the older borehole GS-2 SE of Petrovo village (Varga, 1970a). In our opinion the inherence of carbonate, veinlets can be the possible symptom of productive ore bearing beds neighbourhood.

Owing to shallow positive gravity anomaly is almost impossible to expect larger volume of Fe carbonate bodies in this space. As additional criteria, the interpretation the VES data have been considered, but distance of profiles 200 in this case seemed to be inadequate for exact situation of the borehole.

Prospecting results discussion

The all seven boreholes, to drill in the framework of the project (Lörincz et al., 1994) have been negative from the subject of the prospecting. It is very serious signal for expectation another occurrences of Fe carbonates in this area. There is the place to discuss about reason of such results obtaining and whether is possible to set some perspective places.

Reasons

The all-remarkable positive gravity anomalies in the area in question have been checked. It means that besides two anomalies detected above known deposits (Manó–Gabriela and Kobeliarovo) all the others (Petrovo and Henckovce) have being generated by the rocks complexes, which were not the subject of the prospecting and

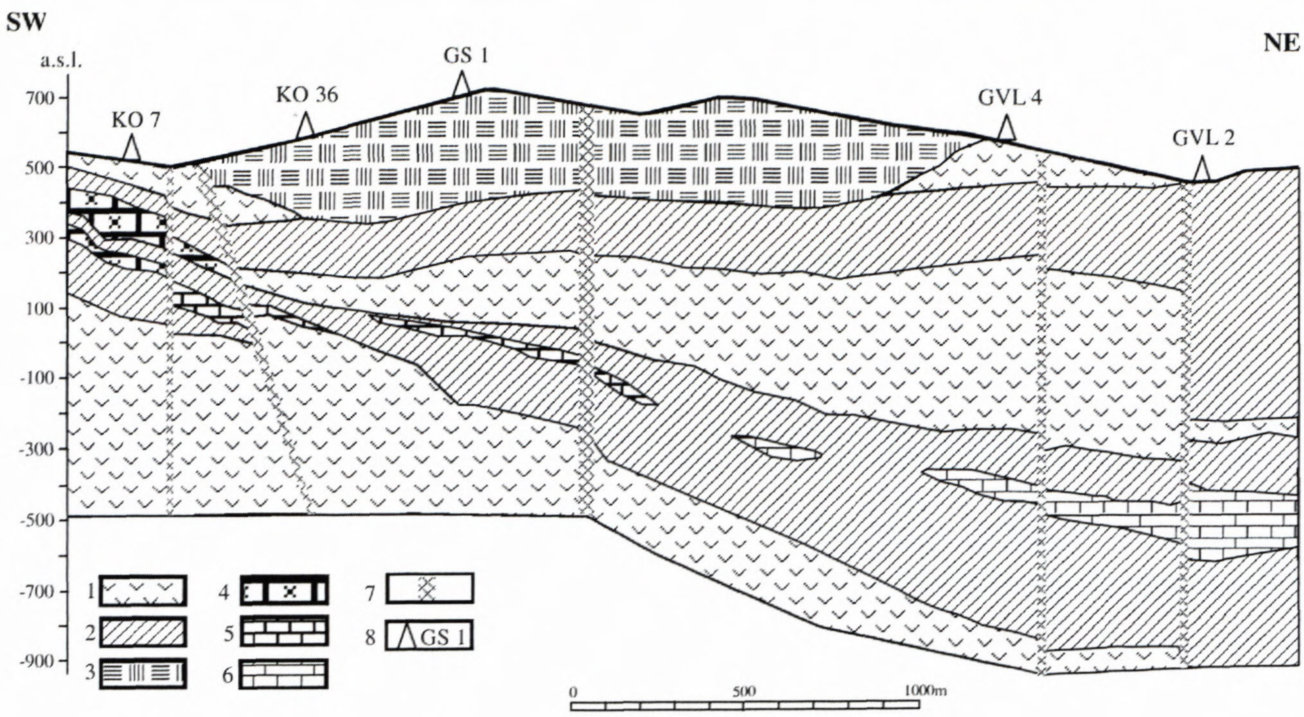

Fig. 6. The example of metamorphose increasing – resulting of gradual conversion from siderite to magnesite between the Kobeliarovo deposit and the GVL boreholes area (to the west of Vlachovo village), compiled by Kucharič, 1997.
1 – porphyroids together, 2 – black phyllites together, 3 – siderite, 4 – ankerite, 5 – magnesite, 6 – faults, 7 – boreholes

source of anomalies has been not syngenetic but it has been generated by the composition of anomalous impacts of various rocks types.

According to our consideration given at the beginning of this paper, the first attention has been concentrated on the positive gravity anomalies. Unfortunately, the source of anomalies Petrovo and Henckovce has been confirmed, but only from physics point of view. The sources of complex anomaly (gravity, resistivity, induced polarization and mercury) were besides of above-mentioned remarks created unusual rocks types, from petrophysical point of view.

It is caused by insufficient knowledge about physical properties of rocks. In spite of the fact that a large portion of the West Carpathians rocks complexes were studied in the last 30 years, the main attention has been concentrated at the assessment of average values and dispersion characteristic only. If we take to consideration the Gauss´ curve of a distribution of an accidental selection, the typical values for a statement of the characteristic features studied rocks complex are modal one. Nevertheless, deposit areas seemed to be often anomalous objects itself, and therefore they are reflected by equally anomalous physical values, which create the marginal parts of the Gauss´ curve, and therefore they are not typical ones. Thus, quartz rocks and quatziferous rocks are usually considered as the light ones, but if they are long time under weathering processes, an abundance of iron minerals in these rocks is often appeared (Kuhnen et al., 2000). This premise is respectable satisfied by temporary interpretation of the completely Early Paleozoic rocks assemblage from the time standpoint. Due to the density of quartziferous rocks is increased as we learned in the boreholes.

The connection between petrophysical features assessment and a particular petrographical description, chemical analysis is dominantly missed, therefore a reason of physical anomaly leaves unknown. The work as has been given by Varga, (1966) is only the objection, which confirms of the rule. This is very weak and unfortunately, the typical feature of petrophysical studies in the West Carpathians region.

It is necessary to stress that prospecting in such complicated litological and tectonic conditions requested higher density of profiles as has been used in this event. The distance of 200 m seemed to be a bit inadequate. That is the most probable reason, why the boreholes NSO -5 and NSO-6 did not reach the ore-bearing horizon.

In the case of an accidental small positive gravity anomaly occurrence (smaller than anomaly caused by Kobeliarovo deposit) which would be due to the scale of the investigation omitted, such object cannot be remarkable for practical exploitation. The deeper situated siderite bodies (hanging wall more than 400m below surface) have not been detected. The explanation of this is in accordance with a metamorphic model of siderite mineralization (Radvanec in Grecula et al., 1995) according to this siderite seemed to be low metamorphic product, (green slate metamorphic facies) whereas magnesite is connected with the higher level of metamorphose – closer to amphibolite facies (ankerite is situated between its). In our case, we suppose an increasing of metamorphose to-

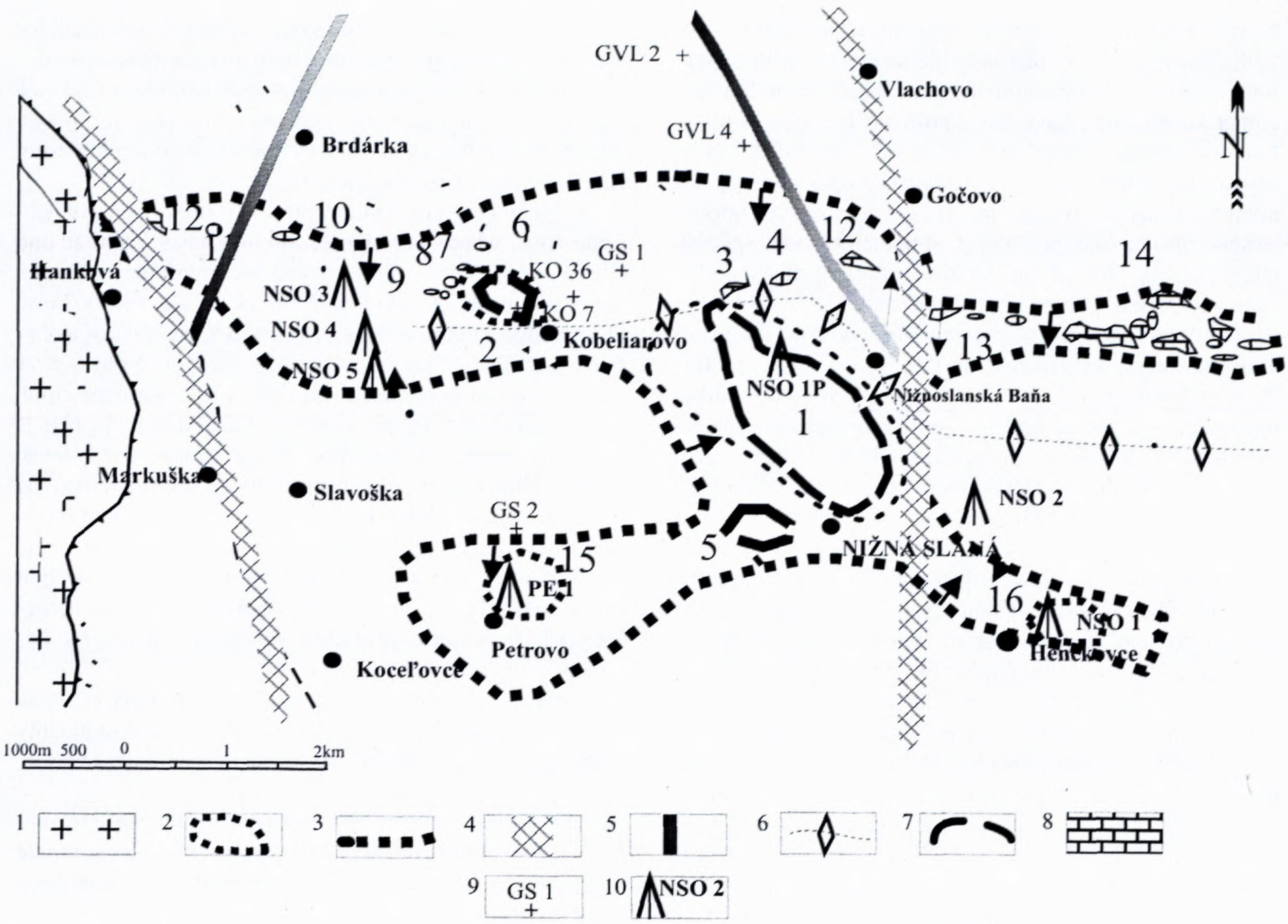

Fig. 7. The sketch of anomalous zones, tectonic delimitation of ore and drilling works.
1. Veporicum unit together, 2. Positive residual gravity anomaly, 3. Extension of regional Hg anomaly, 4. Main faults, 5. Faults „en echelon", 6. Interpreted anticlinal axis, 7. Ore bodies outline projection to the surface, 8. Known Fe carbonates bodies and verified gravity anomalies: 1) Manó – Gabriela, 2) Kobeliarovo, 3) Ignác, 4) Gampe¾, 5) Manó – depth, the south, 6) Jarok baòa – ankerite, 7) Vybraná Michaeli – siderite, 8) Amália – ankerite, 9) Kobeliarovo – ankerite, 10) Álmoš – siderite, 11) Hanková – Brdárka – ankerite, 12) Gočovo – ankerite, 13,14) Zoltán, Atilla, Koloman, Viktor, Leontína, Peter, Bonaventúra – ankerite, 15) Petrovo gravity anomaly, 16) Henckovce gravity anomaly; 9. Selected old boreholes, 10. New boreholes

wards the depth. This model is fully proved and demonstrated on the Fig. 6. (The schematic cross section through boreholes from the Kobeliarovo to the Vlachovo area). The loosing of iron component with increasing metamorphose level connotes increasing of Mg amount what results to diminishing of volume density of this raw materials.

That is the reason why extensional positive gravity anomalies expected from deeper parts of the locality are not detected. If any positive gravity anomalies were appeared, in term of this metamorphic model they could to be generated by magnesite disturbing bodies only. From the previous works is visible (Lörincz et al., 1989) that in he depth bellow 0 m a.s.l. are siderite bodies developed only scarsely in the thin attitudes.

Due to the whole part of the locality on the eastern riverside of Slaná is not perspective from occurrence of siderite bodies, because in the bottom part of the borehole NSO-2 the higher level of metamorphose has been observed – biotite facies (Pramuka, in Lörincz et al., 1997). Furthermore, the lack of the positive gravity anomalies supported by detection of thick complex of porphyroids forced to classified this part of the locality as the non-perspective.

The belt of Fe carbonates Hanková – Volovec to the north of the borehole NSO-2 comprises ankerite and dolomite members only.

The results of the boreholes NSO-2 and NSO-1P (underground) mainly adverted, that function of the Late Variscan nappes tectonic has been a bit overestimated in this case. The porphyroids bored in the bottom part of the borehole NSO-1P were very compact, without some demonstration of tectonic reprocessing. If we compare imaginations of geological structure of the area given on the Fig. 2 with the Fig. 3, based on data from the other boreholes, as well as previous boreholes data is very probable, that geological structure of the area due to Abonyi (1966) has legitimacy. Similarly, the detailed prospecting on the magnesite-talc deposit Gemerská Poloma, approx. 13 km to the east of the locality, verified by boreholes does not embody the relevant feature of nappe structure (Killík et al., 1992, Kucharič, 1993). Equally the results of the deep seismic profile G – 1 situated in the central part of the Spišsko-gemerské ore Mts. have not confirmed the system of the Late Variscan nappes, in spite of theoretically very convenient differences in the waves propagation on the interpreted nappes boundaries. Based on above-mentioned seismic results the geological structure of the Spišsko-gemerské ore Mts. as the Alpine north-vergent nappe has been interpreted. (Vozár et al., 1996).

If we compare geological situation given on the Fig. 1 with interpretation depicted on the Fig. 6 – cross section through known boreholes – is obvious, that belt of carbonates bodies is in the underlying bed of rocks complexes belonging to Vlachovo Formation, which is due to geological map of the area (Bajaník et al., 1984) as the oldest member of the Early Paleozoic sequence interpreted. This is very serious discrepancy pointing out, that the geological map is not in concordance with our interpretation (Fig. 1). The complex of black schists is divided on the eastern bank of Slaná river to two Formations (Bystrý potok and Vlachovo one) according to occurrence of carbonates and lydites. The black schists with lydites bodies are incorporated to the Bystrý potok Formation, while the same rocks with the presence of carbonates bodies belongs to Vlachovo Formation. On the western bank of Slaná river is situation in this map ambiguous and anticline structure has disappeared (the northern limb) in the space under younger carbonates of Radzim hill. (See cross section 3 – 3´ in the map Bajaník et al., 1984). This interpretation would not be accepted situation given on the Fig. 2.

Based on physical features of the black beds – the Betliar one – (induced polarization, spontaneous polarization and apparent resistivity), as well as radioactivity and content of Hg, we consider both, bodies of lydites and carbonates as components of non divided Betliar beds on the locality. This is in accordance with the definition of the beds due to Grecula (1982). Similar interpretation of the Betliar beds based on the deposits areas data from the most important deposits of the Spišsko-gemerské Ore Mts. has been given by Tréger et al. (2003). From this aspect the whole area of Spišsko-gemerské Ore Mts. had to be interpret, for creation of metalogenetic models and raw material prognosis.

The existence of a parasitic synform in the anticline (the northern limb of anticline) setting up by Sasvári et al. (1996) between abandoned deposits Ignác and Gampeľ is possible, but from ore body occurrence viewpoint there are several serious objections:

– there is not detected any larger positive gravity anomaly in this space. The estimated exploited quantity of siderite was about 3 000 kt in the Ignác deposit and 500 kt in the Gampeľ one. For comparison, the Kobeliarovo deposit posse's amount almost 9 500 kt economical reserves. Together with non economical storage the deposit generate positive gravity anomaly + 2 mGal (Ščuka, 1982)

– the Hg anomaly is present in this place, but it is only sufficient condition for occurrence of Fe ore body,

– the space between these two deposits is too small for expectation of larger ore body with an economic benefit,

– in the case supposing of deep-seated minor fold (see Fig. 4) we could reach the higher level of metamorphoses, where occurrence of siderite is due to metamorphic criteria (Radvanec, 1995) is excluded,

– Ignác-Gampeľ fault represents very intensive tectonic zone, where were lenses of carbonates fractured and decomposed. The carbonates are becoming plastic by the temperature about 200 °C (Nemčok et al., 1995). From this standpoint is interesting to compare position of Kobeliarovo deposit. This is in the same structural position as the position of both discussed object (the northern climb of the anticline). In the case of Kobeliarovo deposit is interlimb angle of anticline bigger (open fold sensu Fleuty, 1964)) and probably therefore less disturbed by the tension faults what resulted to surviving of more quantity of ore bodies in this deposit (compare Fig. 2 and Fig. 6). The interlimb angle depicted on the Fig. 2 is tight (tight fold, (Fleuty, 1964)) and tension faults of Ignác-Gampeľ fault took probably substantial place by destruction of carbonates bodies.

– finally, the drill prospecting of deep parts of Ignác deposit was negative and Gampeľ deposit is tectonically amputated in the depth 50 m under surface (Mihók, 1994).

The all these points naturally do not bracket a possibility of occurrences of small, or smaller Fe-carbonate bodies, but with regard to its supposed reserves is very inconceivable to expect an ore body suitable for nowadays miner and economical conditions in this area.

If we take to consideration the all occurrences of siderite on the locality (Fig. 7), they are strongly amputated by faults of quasi-meridian direction – Štítnik fault in the western part of the area and Slaná River fault in the eastern one. The more clean-cut is in the northern part of these main faults according to faults types „en échelon" – divergent faults (Hills, 1963). There are Brdárka fault in the western part and Gampeľský potok in the eastern part of the locality. There are not any occurrences of siderite bodies out of this en echelon area. It would mean that this block boundered by above-mentioned faults is sunken against neighbouring ones. The function of Štítnik fault by the demarcation ore deposits – especially part south of Brdárka village has been defined by Snopko too (1990). Besides, of this we can observe dextral movement (stress of folding) on the Slaná River fault. The southern limb of productive beds is replaced along N – S direction (see Fig.2, or Fig.7) to the South. The stress towards the west (Kobeliarovo) gradually is decreased based on form of anticline. In term of Nicolas (1984) this fault can be as oblique slip classified. The block situated on the eastern bank of Slaná river seemed to be relatively deeper due to higher degree of metamorphose and big distance between limbs of anticline – what in our interpretation represents the lover, or bottom part of anticline. The southern limb was probably drilled near Henckovce village, but without carbonate facies development and near Petrovo village, where in the bottom parts of PE-1 borehole, where lydites attitudes were found only. Its continuation to the east is going to the northern slopes of Turecká hill, where an occurrence of carbonates with the dip to the south was observed (southern of Betliar village), out of our area.

Consequences

The main task of works that had been carried out on the locality Nižná Slaná had to find new siderite body, convenient for exploitation. Besides of this to support or reprove probability one of the both geological structure imaginations, or at least to contribute to discussion about this problem. The summarization of obtained results and verification of interpretation by the boreholes results are as follows:

- The one of the basic keystones in geology - principle of analogy – especially in deposits areas is valid within the very narrow interval only, and above-mentioned experience shoved, that existence of 5! identical favourable symptoms has not to be sufficient for obtaining positive picture about ore perspective in this area. From the deposit viewpoint it is necessary very carefully, to manage by generally accepted this principle which use to be usually one of the most powerful feature by an assertion of projects proposals.
- Results obtained from the all boreholes have been unfortunately negative from the deposit viewpoint. The four boreholes have been drilled on the base of geophysical methods interpretation; next, three were situated according to geological data imagination.
- The presence of the carbonate bodies in the depth is always reflected on the surface by the higher or high content of mercury in the soils, but this dependence is not reverse.
- On the other hand the results from the boreholes have confirmed that preposition of Late Variscan nappes structure of the area in the form given by Grecula (1982 is not quite well founded and therefore should be corrected. The geological map of the area (Bajaník et al., 1984) points out ambiguosities with regard to development of productive black beds, and therefore its using for solution of deposit problems in this area is limited.
- The old geological picture – an existence of the anticline structure – anticline of ore bearing horizon – given witness by Abonyi (1966) has been confirmed by the drilling works and therefore this imagination ought to be directory for solution of various geological problems not only in the area in question but also in the whole territory of Spišsko-gemerské Ore Mts.
- The locality is typical example of area, which is considered as well known and inspected on the very high level, but by solution of determinant deposit problems we meet to shortage of geological structure basic definition.
- A similar structural position of potential ore object as Manó–Gabriela deposit could be possible expect to the south of Kobeliarovo village, but old boreholes were negative here.

Conclusion

The complex of geological works had been performed in the last decennium of the previous century for the purpose to find new siderite bodies, suitable for exploitation. Because of ore bodies have been expected in the form of the hidden deposits, the complex consist of geophysical and geochemical methods, together with the geological mapping. An additional geological mapping, geochemistry analyses, mercury content determination in soils, gravimetry, resistivity and induced polarisation profiling and vertical electrical sounding. The all-previous knowledge about geological structure of the locality and results from the old boreholes and mining works had to take to consideration.

The places for the situation of the drilling works had been selected on the base of gravity positive anomalies detection and on the base of supposition geological structure development.

The seven boreholes have been drilled in the adjacent area of Nižná Slaná deposit area, as well as in the deposit itself for purpose spreading of ore storage. The four boreholes, PE-1 (Petrovo), NSO-1, (Henckovce area), NSO-5 and NSO-6 (Brdárka area) were located on the base of geophysical and geochemical indications. These indications were very similar, as indication directly reflected by the ores bodies of the Fe carbonates. Next four boreholes were traced a posteriori of geological imaginations – the borehole NSO-2 in the Henckovce area, the boreholes NSO-3 and 4 in the Brdárka area and finally the inclined borehole NSO-1P situated in the underground directly in the deposit Manó-Gabriela. The last drill-hole had to besides of new ore bearing horizon discovering, to confirm the variscan nappe structure of this region simultaneously.

In spite of finding several suitable anomaleous objects (very similar to anomaleous object directly above deposit detected) the results obtained from the all boreholes have been negative from the deposit viewpoint. Presence of positive gravity anomalies was the most important, but not only criterion by assessment of Fe carbonates prognosis in the area in question. The metamorphic model of siderite creation as well as tectonical delimitation of ore mineralization were take to consideration.

The all results obtained have been analysed by critical approach pointing to „gaps" in our wraparound knowledge about strata bound siderite bodies development.

On the other hand the results from the boreholes have confirmed that preposition of variscan nappe structure of the area is not well founded and therefore should be corrected. The old geological picture – an existence of the anticline structure – given witness by Abonyi (1966), has been confirmed by the drilling works and therefore this imagination should to be directory for solution of various deposit problems not only in the area in question but also in the whole territory of Spišsko-gemerské Ore Mts.

Based on above mentioned reasons and the conclusions we can proclaim: The new occurrence of Fe carbonate bodies in the area in question which would be satisfied to up-to-date economic and exploitation conditions is practically excluded.

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Lithological formations in the regional engineering geological rock classification

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Abstract. In the half of the previous century the regional engineering geological classification of rocks in Slovakia identified 10 lithological formations, 8 subformations and 75 lithological lithological complexes. Recent research has called for certain modifications of names, stratigraphic and spatial extent of some formations and subformations, and, mainly the number of lithological complexes defined within individual formations. The contribution deals with the issue and it gives suggestions for some modifications, mainly at the formation and subformation level. In the future, it will be inevitable to compile a revised engineering geological classification of rocks in Slovakia, in which all lithostratigraphic units depicted in recent editions of regional geological maps would be attributed to individual lithological formations.

Key words: lithological formations, Western Carpathians, regional engineering geology

Introduction

In the engineering geological rock classification we used two basic classification types. Detailed classifications are used at the rock environment characterization in the project stage in civil engineering. These classifications distinguish rock massif bodies of a high degree of physical properties homogeneity. These entities are of a rather small extent and generally, there is not possible to depict them in maps. Regional engineering geological classifications are used for purposes of larger rock environment volumes delineation, which reflects their tectonic development, rock origin and lithological character and at the same time a certain degree of homogeneity of those properties of rocks, which are significant from the engineering geological point of view.

In the second half of the previous century a four-level classification of rocks has been adopted in the countries of Central and Eastern Europe, later also in the scope of the International Association of Engineering Geology (IAEG), to meet requirements of engineering geological mapping. This classification has distinguished the following hierarchically arranged lithological units: lithological formation, lithological complex (LC), lithological type and engineering geological type (IAEG-UNESCO, 1976). The criteria applied in this classification, as well as lithological and engineering geological significance of delimited rock units presents Table 1. There are several countries (Slovakia included), which have established also another rock unit - lithological set, located between lithological complex and lithological type. It has enabled to distinguish also lithologically differing parts of lithological complexes, according to their facies development (for instance within the fluvial complex lithological set of flood-plain deposits, which is typical by irregular alternation of sandy and loamy-clayey sediments). Matula (1969) applied the classification system for the territory of the Western Carpathians. Within the first two lithological units he distinguished 10 formations, 8 subformations and 75 lithological complexes. Whereas the lithological complexes delineation has witnessed considerable changes, the lithological formations remained unchanged regarding their number and name. Based upon recent research their lithological content has been partially changed, together with their stratigraphic and space extent.

Lithological Formation Definition

The main factor, which controls petrogenetic processes and structural arrangement of rocks is the geotectonic evolution of a territory. Regarding sedimentary rocks a significant role playalso paleogeographic conditions. These factors are decisive in activation of formation's origin conditions as well as its lithological content. The advance in the knowledge about formations within the engineering geology was developed mainly by the half of the previous century. Among the foreign authors, who significantly influenced the Slovak engineering geological science, we have to mention Belousov (1954) and Popov (1957, 1961, 1965). However, the term formation was at the same time used in regional and tectonic geology. Andrusov, Mahel' and many others used it in their works. Nowadays, the term is frequently used abroad, mainly in USA and Canada. In Slovakia, the term formation has been abandoned with only exception of volcanology, by the end of the previous century. This was influenced mainly by non-equivocal opinions, how to define it, as well as by problems in translation of the term from English, while the term formation has been translated as lithological suite, series of strata, or formation.

Some older studies understood under the term formation only its stratigraphic meaning, which has been re-

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Slovak Geol. Mag., 10, 3 (2004), 227 – 233

Tab. 1. Definition and content of rock units identified in the regional engineering geological classification.

Rock unit	Definition	Geological-lithological meaning	Engineering geological meaning
Lithological formation	Paragenetically associated lithological complexes, which petrogenesis and physical properties forming was conditioned by mutual geotectonic and paleogeographic evolution	Occurrence of certain lithologic rock complexes in certain spatial (superposition, mode of alternation) and proportion (prevailing complexes and their characteristic thicknesses) arrangement	Stratigraphic-lithologic model of the rock environment, which enables to determine its lithologic variability and susceptibility to geodynamic phenomena
Lithological complex	Set of rock lithological types of the same genesis, which was formed in certain part of a lithological formation, in different petrogenetic evolution conditions	Occurrence of certain petrographic types or their sets (facies complexes), in a certain spatial and proportion arrangement	Type model of lithologic conditions, which enables a preliminary assessment of foundation soil complexity and properties
Lithological type	The rock type of certain mineral composition, fabric and structure, which was formed within a lithological complex in relatively constant petrogenetic or lithofacies conditions	Occurrence of in certain way associated characteristic mineral grains and accessories, forming according to their quantitative portion petrographic rock types	Petrographically homogeneous rock body, which enables a rough determination of physical properties values interval and durability against exogenous agents
Engineering geological type	The rock type defined within a lithologic type of homogeneous physical state resulting from petrogenetic evolution and the same degree of tectonic and hypergenous alteration or water saturation	Petrographic rock types of the same degree of jointing, alteration and weathering, or consistency and relative density	Petrographically and physical-technical homogeneous bodies, which can be characterised by a set of statistically estimated physical properties

Tab. 2. Lithological formations and lithological complexes of the Western Carpathians[1]

Lithological formation	**Age**	**Lithological complexes**
Quaternary Cover Formation	Quaternary	fluvial, proluvial, glacial, glaciofluvial, deluvial, eolian, polygenetic, organic, chemogenous
Molasse Formation	Neogene	limnic and limnic-fluvial brackish shallow-neritic and littoral
Neovolcanites Formation	Neogene (Quaternary)	basalts and basaltoid andesites, their tuffs andesites, their tuffs and tuffites rhyolites and rhyodacites, their tuffs and tuffites
Flysch Formation	Late Cretaceous – Paleogene	prevailingly claystone-marlstone typical (rhythmic) flysch prevailingly sandstone basal – coarse-detritic
Sandstone-Marlstone-Limestone Formation	Late Triassic – Early Cretaceous	flyschoid marly-calcareous pelitomorphic limestone detritic-carbonate detritic Carpathian Keuper
Limestone-Dolomite Formation	Middle-Late Triassic	Lunz Member shales dolomites limestones and dolomitic limestones
Lower Terrigenous Formation	Late Permian – Early Triassic	variegated Werfen shales beach quartzites variegated shales with melaphyres variegated detritic Verrucano
Variscan Granitoids Formation	Early Carboniferous	leucocratic granitoids autometamorphosed granites and granodiorites syntectic (migmatitic) granitoids granodiorites to quartzose diorites granites to granodiorites (tonalites)
Epimetamorphosed Rocks Formation	Paleozoic	shales and phyllites, volcanic-carbonatic conglomerate, basic initial intrusives phyllitic, metadiabasic phyllitic, metaquartzite, porphyroid
High-Metamorphosed Rocks Formation	Algonkian-Early Paleozoic	gneissose, mica schistose, orthogneissose, migmatitic, amphibolitic, diaphtoritic gneissose, lit-par-lit gneissose

[1] Compiled based upon Matula – in Matula, Pašek, 1986

flected also in the Glossary of Geology (Svoboda et al., 1960), in which the formation is equal to the stratigraphic system. According to the Encyclopaedic Dictionary of Geological Science (Svoboda et al., 1983) the Russian authors understand under the term formation an „association of geological bodies (for instance beds) unified based upon paragenetic, genetic, stratigraphic or any other relation". The American terminology defines the formation as „the principal lithostratigraphic unit (prevailingly sedimentary, but also metamorphic or igneous), which can be mapped in the field and is used in the local nomenclature". From the above it is obvious, that the term formation comprises geotectonic, stratigraphic, genetic-lithological, as well as regional meanings, with their common interrelations. The geotectonic meaning is derived from the attribution of the formation to a certain stage of the Earth's crust evolution (within a given area), which, of course took place during certain period and thus, is of a certain stratigraphic range (usually several stages or divisions, eventually subdivisions). Genetical lithological meaning is related to the occurrence of rocks of certain genesis and lithological character. Regional aspect is usually expressed by the local formation name. Sometimes, geotectonical or lithological names of formations are used instead of local terms. The above meanings correspond to various formation names used in various countries. The terms geological formation, geotectonic formation and lithological formation can be also met in the geological literature. Whereas, in the Slovak regional geology the term formation is used only to define rock units within volcanic complexes, in the regional engineering geological nomenclature is in common use the term lithological formation.

The difference in formations delimitation between the geology and engineering geology is also in their spatial extent. In the regional geology the term formation has been adopted for rock complexes of local or smaller region extent, in the engineering geology it is applied for the whole Slovak territory (or Western Carpathians). It means they have been delineated based upon geotectonical, stratigraphical and lithological approach. In fact, the time-space extent of individual formations is not unique within the whole Slovakia territory. Therefore, the main criterion at their delineation has been geologic-tectonical and lithological development of the rock environment.

Lithological formations in the regional engineering geological classification of rocks in Slovakia

The lithological formations defined in the engineering geological classification of rocks in Slovakia (Matula, 1969) are derived from the geotectonic and facies-genetic approach, which reflected that time knowledge on the mobile parts of the Earth's crust evolution within the Western Carpathians space. The formations, their stratigraphic range and simplified lithological content are presented in the Table 2. In opposite to the former knowledge, which provided the base for the classification compilation, the opinion upon geotectonic evolution, character and extent of sedimentary basins (mainly the Paleozoic and older), sediments age and their further alterations have been changed. However, the formations delineated relatively reliably reflect the evolution of the rock environment in the Western Carpathians territory. A newly compiled Map of lithological formations (Fig.10) has included a new knowledge on the lithofacies evolution of the Western Carpathians territory, and, accordingly, the cartographic depiction of some lithological formations has been modified.

The Highly-Metamorphosed Rocks Formation

The formation (Fig.1) comprises strongly metamorphosed rocks. It has been subdivided into two subformations - according to the prevailing metamorphosis stage. The lowest row of the formation's cell in the Table 2 presents LCs of the catametamorphites subformation, the upper row LCs of the mesometamorphites subformation. The LCs of the middle row occur in both subformations. A typical feature of both subformations is a relative high uniaxial strength and low deformability, as well as good durability against exogenous agents action. However, some rocks of the mesometamorphites subformation show a relatively higher level of physical-mechanical anisotropy. This is valid for strongly schistose rocks, like mica schists, diaphtorised gneisses and mica schists and phyllonites, which are usually ranked among semisolid rocks group.

Fig. 1. Distribution of the Highly Metamorphosed Rocks Formation.

According to the former opinion the rocks of the formation had been formed in the Proterozoic and than they were folded and regionally metamorphosed (during Assynthian and Caledonian orogeny), but the newer opinions have brought doubts about their Proterozoic age as well as the age of their metamorphosis. According to the present knowledge the lowermost rock complexes were metamorphosed during the Early-Variscan, eventually Caledonian orogenesis phase and the metamorphosis of the upper parts was linked with granitoid magmatic activity during the Late-Variscan orogenesis (Nemčok et al., 1993). Several lithological complexes have been termed differently. The formation's rocks are the oldest and the most metamorphosed rocks in the territory of Slovakia with consequences to the engineering geological character, which has been specified by its subdivision into two subformations and several lithological complexes.

Slovak Geol. Mag., 10, 3 (2004), 227 – 233

The Epimetamorphic Rocks Formation

The formation (Fig. 2) occurs mainly in the Spišsko-gemerské rudohorie Mts. It comprises the Paleozoic, prevailingly epimetamorphosed rock complexes of schists, carbonates, tuffs and tuffites, quartzites, sandstones and conglomerates, phyllites, porphyroides, diorites and gabbros. The formation is divided into three subformations:

- subformation of Caledonian epimetamorphites (Cambrian-Silurian),
- subformation of Early-Hercynian epimetamorphites (Devonian),
- subformation of Late-Hercynian epimetamorphites (Late Carboniferous-Early Permian).

Fig. 2. Distribution of the Epimetamorphosed Rocks Formation.

The subformations correspond to three stages of geotectonical evolution of the Western Carpathians during the Paleozoic. The lithological complex of the oldest subformations have been attributed to the Gelnica Group, the Devonian subformation to the Raková and Harmónia Groups and the youngest subformation to the Ľubeník Group. Recently, mainly in the Veporicum and Hronicum, there have been numerous other groups distinguished: Revúca, Dobšiná, Črmeľ and the other groups (Bajaník, Vozárová et al., 1983), which contain the Paleozoic complexes in partially different lithological facies. Locally, the LCs of the formation have different spatial range than in previous delimitations. In spite of that, the fundamental engineering geological characteristic of the formation's rocks has remained the same. Prevailing are the low-metamorphosed rocks of the metamorphosed schists and phyllites types with a high level of physical-mechanical anisotropy. We rank them among semisolid rocks (the uniaxial compressive strength below 50 MPa), with relatively high compressibility and a low durability against exogenous agents. The other rock types with a lesser extent, mainly the magmatic and carbonate ones show relatively better engineering geological properties and they have been utilised for various purposes.

The Variscan Granitoids Formation

The formation (Fig. 3) occurs mainly in the central parts of the Core Mountains. Lithological complexes given in the Table 2 have been slightly modified, based upon the newest regional geological research; eventually their names have been changed. For instance, the so-called syntectic (migmatitic) granitoids are termed at present as the hybrid granitoids, complex of granodiorites to siliceous diorites have been subdivided into two complexes, in some mountain ranges the tonalites have been distinguished, etc. The definition and the stratigraphic range of the formation have not been changed, yet. Regarding an equal lithological and engineering geological character of rocks, into the formation have been integrated also the granitoid rock of uncertain stratigraphic range (Cretaceous?), which crop out mainly at the contact of the Veporicum and Gemericum in the Slovenské rudohorie Mts. The sound granitoid rocks of the Western Carpathians (with the exceptions of autometamorphosed and kineticly metamorphosed granitoids) show convenient engineering geological properties. However, they are frequently tectonically disrupted: fragmented into blocks, intensely jointed and mylonitized, which significantly decrease their utilisation possibilities.

Fig. 3. Distribution of the Variscan Granitoids Formation.

The Lower Terrigenous Formation

The formation (Fig. 4) is made of rocks ranging from the Late Permian to Early Triassic. According to Matula (in Matula and Pašek, 1986) it represents the opening phase of the Carpathian geosyncline evolution. However, defined lithological complexes present in the Table 2 don't represent all zones. The Veporicum and Gemericum units frequently differ in their Late Permian and Early Triassic evolution, which is reflected by several sequences. For instance, the sediments of so-called Verrucano comprise schists and carbonates (the Meliaticum Group) or sandstone-schistose beds (the Silica nappe), in the Gočaltov Group there are no quartzites and the uppermost horizon of the Early Triassic is of distinctly different facies from the Werfen Schists. A variable geotectonic and paleogeographic evolution within various parts of the territory is documented also by rauhwackes and evaporites occurrences, which at places occur at the bottom Triassic horizon (for instance in the Stratená Group), at other places at the contact of the Early/Middle Triassic (for instance the Meliata Group). This variegated spatially differentiated lithological character of the rock environment reflects complicated geotectonic and paleogeographic evolution during the sedimentary space forming, which had taken place on the Paleozoic/Mesozoic contact. The name and stratigraphic range of the formations are, in our opinion, correct. The future will put the stress upon definition of the lithological complexes in the way they would cover every lithofacies.

Fig. 4. Distribution of the Lower Terrigeneous Formation

The Limestone-Dolomite Formation

The formation (Fig. 5) represents a typical facies of the Carpathian Triassic, comprising limestones, dolomitic limestones and dolomites, locally intercalated by shales. A significant position is given to the Lunz Member (Carnian) with dark pelitic-aleuritic shales, which in the Hronicum unite and partially also in the Silicicum unit divide the Middle- and Late-Triassic dolomites (though, they are not present in the Silica nappe). A different facies has been documented in the Stratená Group, in which the shales contain also the layers of dark, at places cherty limestones. The Meliata Group contains in addition also grey and red silicites, metabasalts and their tuffs. Their superincumbent is formed of limestones (Norian), not the dolomites. In the Tatricum and Fatricum the Lunz Member is overlain by the Carpathian Keuper, which in the valid engineering geological classification belongs to another formation. The delineation of the carbonate Triassic within individual formation is substantiated by the fact, that the formation characterizes a particular epoch of a geotectonic evolution, linked with deepening of the sedimentary space and with change in paleogeographic conditions, as well as with a different lithofacies of the bottom and above formations. Thanks to its specific rock properties the relief, hydrogeological conditions and specific geodynamic phenomena distinctly manifest the formation.

Fig. 5. Distribution of the Limestone-Dolomite Formation.

The Sandstone-Marlstone-Limestone Formation

As a consequence of a gradual shallowing of the sedimentary space the sedimentation of the formation's rock complexes (Fig. 6) started in its northerly parts (Tatricum, Fatricum) in the Carnian, whereas in its southern parts in the Norian (with only exception of the Gemericum, in which carbonate facies sedimentation was continuing). While the Carpathian Keuper represents a variegated terrestrial to lagoon facies, at the beginning of the Liassic shallow-marine facies started to dominate, which is documented by the contribution of detritic material. Typical representatives are detritic and crinoidal limestones, sandstones and quartzites, locally also shales (Gresten Member). During the Later Liassic (occasionally even to the Doggerian) a similar sedimentation was continuing. In the case of the sea deepening eventually spotted marlstones and marly limestones or marly shales originated. During the Doggerian and Malmian pelitomorphic limestone complex was deposited with typical muddy, radiolarian, cherty and nodular limestones deposition. By the end of the Jurassic and at the beginning of the Cretaceous this type of sedimentation continued, forming suites of marly limestones and marlstones, with intercalations of calcareous sandstones. The Albian and Cenomanian, partly also the Turonian, are characteristic by deposition of flyschoid sandstone-marlstone sequences intercalated with limestones, with conglomerate facies at the bottom, which indicates transgression related to the Austrian orogeny phase. With these sequences the Middle Cretaceous formation evolution was closed.

Fig. 6. Distribution of the Sandstone-Marlstone-Limestone Formation.

On the Middle Cretaceous/Late Cretaceous boundary the Central Western Carpathians were folded within the Mediterranean orogeny phase and the Late Cretaceous (with only tiny occurrences) was transgressively deposited upon the Middle Cretaceous sediments. Its greater extent has been documented in the Klippen Belt, in which the flyschoid sediments containing beds of Upohlav Conglomerate overlie the Turonian sediments. Thus, the Late Cretaceous of the Western Carpathians has been ranked to the Flysch Formation.

The Flysch Formation

The Flysch Formation (Fig. 7) in the external zone of the Western Carpathians developed gradually from the

Slovak Geol. Mag., 10, 3 (2004), 227 – 233

Late Cretaceous up to the Oligocene. In the internal zone it developed transgressively in the Eocene. In the Klippen Belt with the Late Cretaceous belonging to the Flysch Formation, the Paleogene invaded the sedimentary space discordantly (after the Laramide orogeny phase). Locally it began in the Paleocene, at places also in the Eocene. The above differences were closely connected with the tectonic evolution of the Western Carpathians in the period from the Mediterranean till Savian orogeny phases. The lithological content of the formation is variable due to differing facies evolution in various parts of the tectonically modified sedimentary spaces. However, it is possible to distinguish within it four types of lithological complexes (see the Table 2). The formation involves sediments of the Flysch zone and Klippen Belt, as well as the sediments of the Inner Carpathian Paleogene. In the first two zones the sediments are intensely folded with nappe structure, the sediments of the Inner Carpathian Paleogene are disturbed only by the germanotype tectonic style and only partially folded. This difference, which is manifested also by tectonic disintegration of rocks, is reflected in the engineering geological territorial zoning. In the region of the Carpathian Flysch there are distinguished subregions of the Outer Flysch Carpathians, the Klippen Belt and the Inner Flysch Carpathians.

Fig. 7. Distribution of the Flysch Formation.

The Neovolcanites Formation

The formation (Fig. 8) comprises all effusive and volcanoclastic rocks of the Cainozoic age. Their stratigraphic range within the Western Carpathians is from the Eggenburgian till Quaternary (with interruptions). The Slovak territory witnessed the most intense volcanic activity during the Badenian and Sarmatian. Besides the lithological complexes, which we present in the Table 2, we distinguish also coarse-porphyric andesites and their tuffs – these rocks show distinctly different engineering geological properties. The fundamental role in the volcanites properties played various post-genetical processes: autometamorphosis, hydrothermal alterations, propylitization, tectonic disruption and weathering. We distinguish within the rock massifs such zones in form of particular complexes; alternatively they are highlighted by proper symbols. The effusive rocks are ranked among solid rocks; the volcanoclastic and intensely propylitized rocks belong to the semisolid rocks, prevailingly. In opposite to the previous formations, which occur within the whole Carpathian Arc, the Neovolcanites Formation crops out only in the Central and Eastern Slovakia and partially also the Southern Slovakia.

Fig. 8. Distribution of the Neovolcanites Formation.

The Molasse Formation

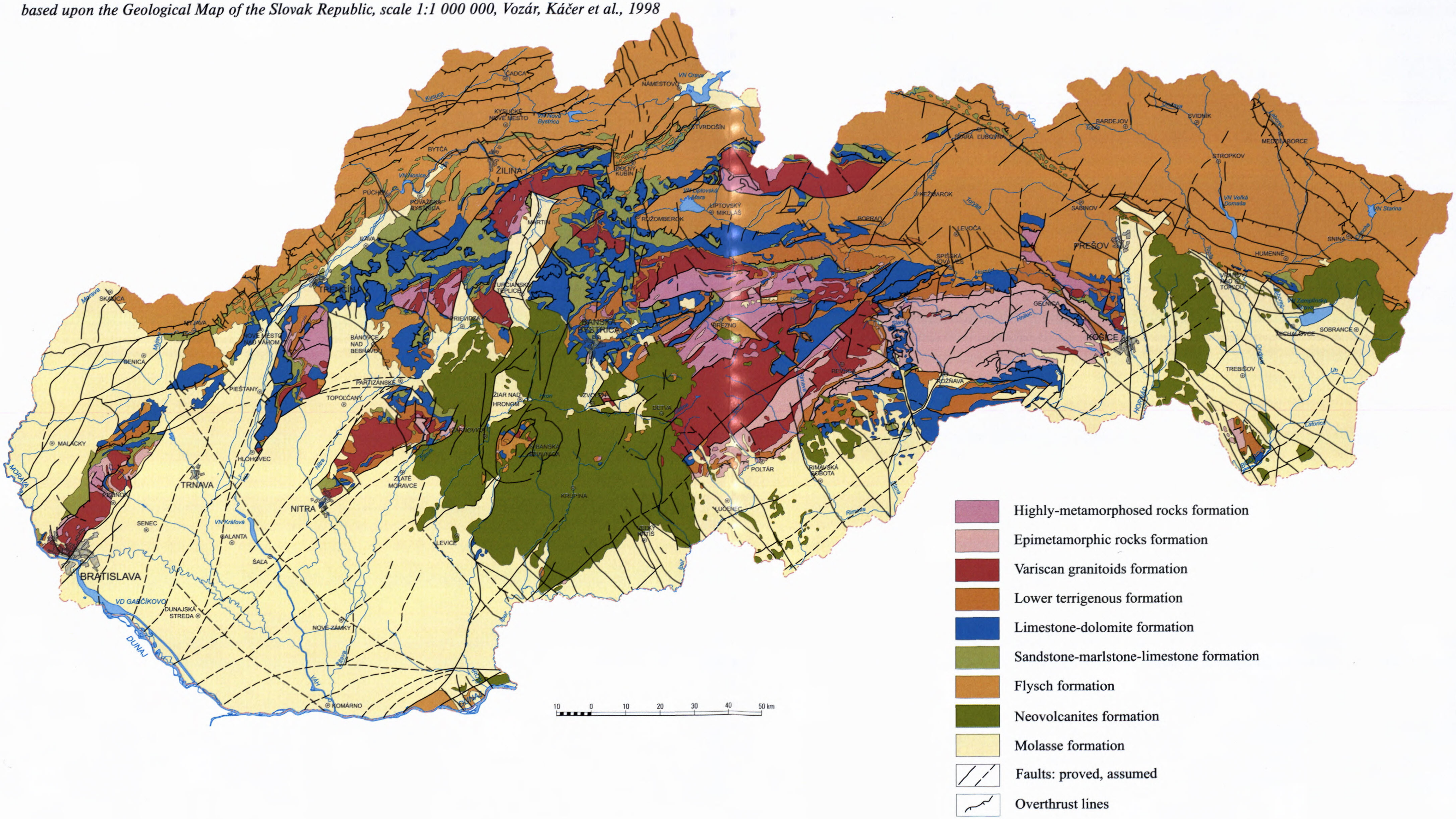
The formation (Fig. 9) occurs in the Foredeep, in the Vienna, Danube, South Slovakia and East Slovakia basins and in majority of the intramountain depressions (Vass et al., 1998). In the area of Foredeep its deposition started in the Egerian, in the area of the South Slovakia (excluding the Cerová vrchovina Upland) in the Kiscelian, in other parts of the Western Carpathians in the Eggenburgian. Its deposition in the Carpathian Foredeep territory lasted till the Early Badenian, in the South Slovakia and along the margins of the Danube Basin till the Pannonian, in other territories as a rule till the Rumanian, at places only till the Sarmatian. During the Pliocene the deposition in some sections of the Carpathian Foredeep was renewed (Seneš in Andrusov and Samuel et al., 1983). Due to tectonic differentiated activity individual Neogene stages have different lithological facies. At places they started with sea-transgression, at other places they continue without any interruption from the below stage. The lithological complexes of the formation presented in the Table 2, which have been distinguished in the regional engineering geological classification of Slovak rocks, correspond to three subformations (s): the Miocene marine sediments s., the Miocene brackish (transitional) sediments s., and the Pliocene lacustrine-fluvial sediments s. Based upon the recent knowledge on the facies evolution of the Neogene sediments it would be convenient to abandon the names of the divisions (Miocene, Pliocene), because the lacustrine-fluvial subformation was deposited in the Badenian, Sarmatian and Pannonian (except of the Vienna Basin and the central parts of the Podunajská nížina Lowland) and the transitional (brackish) sediments occur in variable stratigraphic position (ib.). Regarding the above facts it would be suitable to rename the lowest subformation to the subformation of marine and brackish sediments and to single out the brackish sediments subformation only for the territory of the Vienna Basin and the central part of the Podunajská nížina Lowland. The lithological content of the marine and brackish involves gravelly-sandy, conglomerate-sandstone and clayey-silty (frequently marly) sediments; the subformation of the brackish sediments is made of gravelly-sandy, clayey-silty and

MAP OF LITHOLOGICAL FORMATIONS

for purposes of regional engineering geological assessment of the territory of Slovakia

Authors: Pavel Liščák, Miroslav Hrašna

based upon the Geological Map of the Slovak Republic, scale 1:1 000 000, Vozár, Káčer et al., 1998



tuffaceous clayey-silty sediments; the lacustrine-fluvial subformation is composed of gravelly-sandy and clayey-sandy sediments with sandy layers. In several depressions the Badenian sediments of the latter subformation are of volcanic-limnic facies, containing carbonate conglomerates at the base (e. g. the Budiš Formation). The younger lacustrine-fluvial sediments are characterised by a lower relative density degree, or consistency when comparing with marine and brackish sediments.

Fig. 9. Distribution of the Molasse Formation.

The Quaternary Cover Formation

The Quaternary of the Western Carpathians represents a particular evolutionary stage, which is typical for continental facies of irregular spatial distribution. The largest extent and thickness have developed in the lowlands and depressions, in opposite to high mountains. The largest thicknesses (reaching several tens of metres, even above 100 m) have been documented in the Quaternary tectonic depressions of the Záhorská, Podunajská and Východoslovenská nížina lowlands and the Liptovská kotlina Basin. The fill of these depressions consists of deluvial, proluvial, eolian, fluvial and glaciofluvial deposits. In ordinary development the largest thicknesses have been observed in glacial, deluvial, eolian, fluvial and glaciofluvial sediments (usually up to 20 to 30 m). The physical-mechanical properties of the Quaternary sediments (of the same genesis and type) vary depending upon the age, position, hydrogeologic conditions and geodynamic phenomena (slope failures, collapsibility, suffosion, volume changes, etc.). Concerning usually small extent of the formation outcrops, as well as the fact, that in some areas of its greater extent it would overlap older formations or their borders, the formation is not depicted in the Fig.10. The lithological complexes of the Quaternary Cover Formation are presented in the Map of Engineering Geological Zoning 1:500 000 published in the Landscape Atlas SR (Hrašna and Klukanová, 2002).

Conclusions

The lithological formations in the engineering geological classification of the rocks of Slovakia were distinguished based upon geotectonical and genetical-facies principles, which reflected the former knowledge from the half of the previous century. While the geotectonical approach, which reflects the main evolution stages of the Western Carpathians geological setting, can be considered as the correct one, the knowledge on the geological complexes facies, or their stratigraphic range and spatial distribution has been considerably shifted in some regions, when comparing with former interpretations. The presented Map of Lithological Formations of Slovakia (Fig.10), which was constructed based upon the Geological Map of Slovakia at 1:1 000 000 scale (Vozár and Káčer et al., 1998) has taken into account the spatial distribution of individual formations reflecting the recent knowledge. However, the scale of the map did not allow depicting some of their smaller occurrences. In the future it will be inevitable to construct more detailed maps, which would comprise all relevant stratigraphic-lithological units attributed to individual formations. The first step towards this goal might be the updating of the regional engineering geological classification of rocks at the level formation-subformation, in which these formations would comprise every lithostratigraphic units, which have been identified in the Geological Map of the Slovak Republic 1:500 000 (Biely et al.,1996).

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Slovak Geol. Mag., 10, 3 (2004), 235 – 238

Map of parameters of the current flows in surficial layer-effective tool for proper location and protection of underground mettalic constructions

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Abstract: The paper deals with the Map of parameters of the natural and artificial current flows in surficial layer of the rock medium, constructed in Vranov – Humenné – Strážske region.

The target of this study was determination of presence and parameters of current flows of the natural origin (electrochemical, filtration, diffusion and telluric current fields) and from artificial sources (cathode protection of the burried pipe lines, vagabond flows, etc.).

Following parameters have been determined: density of current flow and its course as well as resistivity of the surficial layer. Depth penetration of the measurements: 3.75-6.25 m below surface. The density of the observations: 1-4 stations per sq.kms. The results obtained have been compared with valid Slovak technical norms. As a result of this comparison, the area in question has been divided accordingly the aggresivity degree of geological medium on various metallic constructions.

Key words: surficial layer, current density, soil resistivity, soil aggresivity for metallic constructions

Intruduction

In the present, huge construction activities are performed in Slovakia and abroad. It is generally known, that underground metal constructions need anticorrosion measures and active cathode protection in case of higher soil aggresivity. The degree of aggresivity depends on current flow density and course as well as on resistivity of the surficial layer. That is why the information on spatial distribution of these parameters of the natural and artificial current flows are very important for proper location and protection of the underground metal constructions and pipe lines.

This paper deals with results of determination of the presence and parameters of the electric current flows in surficial layer of the rock medium in Vranov-Humenné-Strážske region. These observations have been done in frame of the project: „Maps set of geological factors of the environment in Vranov-Humenné-Strážske region", performed in 1998-2003 period.

The subjects of study have been current flows of natural origin (electrochemical, filtration, diffusion and telluric ones) and originating from artificial sources (active cathode protection of burried pipe lines, industrial currents, etc.). These flows posses various density and courses. The resistivity of surficial layer, which is other parameter influencing the soil aggresivity on metal constructions, has been determined too.

The measuring stations have been located with different density. In the area of Vranov, Strážske, Humenné and Snina towns, the density varied in the interval of 2-4 points per sq.km, while in other regions 1 point/km^2 was measured.

Geological setting of the area under study

The area under study is built by Mesozoic, Paleozoic, Paleogene and Neogene formations. The Quaternary is presented by proluvial, fluvial, deluvial, eolic and eolic-deluvial sediments. Following geological units can be distinguished: Čergov-Beskydy flysch, klippen zone and nearklippen area, Central Carpathian Paleogene, Slanské vrchy neovolcanics, Eastern Slovakia basin, Humenné hills and Vihorlatské vrchy neovolcanics.

The substantial part of the area belongs to Čergov-Beskydy flysch, built by sandstones and claystones. The Quaternary evolution has been influenced by surface presence of the various type of Magura nappe rocks. Easy weathering of claystones caused the rise of thick layers of deluvium on the slopes. The typical flysch (alternation of claystones and sandstones) is more resistant to weathering and linear erosion is frequent here.

The narrow strip of the area is built by klippen zone with predominant carbonates and flyschoid sediments. The klippen zone is divided from Central Carpathian Paleogene by rocks of outer flysch zone. Generally, the klippen belt is typical by the smallest thicknesss of the Quaternary sediments.

The Paleogene claystones of sub-Tatras group very easily weather and they create smoothly modelled hilly country. Ocassionally presented conglomerates create steeply cutted valleys with development of outwash cones at their estuary.

The neovolcanics of Slanské vrchy hills create hilly, frequently sharply cutted relief. The positive morphostructure of Slanské vrchy hills has been subject of intensive weathering processes during Pleistocene. The weathering products were transported to lower part of the mountain. This process, togehter with active tectonics, caused the thickest accumulations of Quaternary sediments in the area under study (more than 30 m).

The Eastern Slovakia basin is namely built by Neogene pelites. The relief is in the form of water cut valleys with accumulation of Quaternary sediments in central part and smooth slopes with development of deluvium on their foots.

The southern margin of the area is created by Mesozoic rocks of Humenské vrchy hills and by neovolcanics of Vihorlatské vrchy hills.

The thickness of Quaternary sediments is result of complicated geological-geomorphological processes during the youngest geological period. It is conditioned by lithology of Pre-Quaternary basement, its morphology and by development of individual genetic types of Quaternary sediments, which are expressed by own geomorphological form. The maximum thickness of Quaternary reaches over 30 m (at Soľ village), but predominantly varies in the interval of 0-2.5 m.

Methodology of the field measurements

For location of the measuring stations, the topographical maps of 1:25 000 scale have been used. The values of potential differences, of which knowing is necessary for calculation of the current flow density and determination of its course, have been measured at every station in two directions: N-S and W-E.

The potential differences (ΔV) have been measured between two nonpolarizable electrodes ($Cu/CuSO_4$), distant 20 m. The measurements of ΔV have been performed in both courses simultaneously, by two digital multimeters. The measuring time at one point has been chosen after changes frequency of the ΔV values-from ca 7 minuts to 15 minuts as a maximum in case of intensively disturbed electric current flow. The multimeters registered ΔV changes in one second intervals. By connected portable computers, the average ΔV values with determination of their polarity were obtained.

After finishing ΔV measurements the apparent resistivity (ρ_a) measurements have been carried out at the same courses. The ρ_a observations have been performed utilizing Wenner electrode configuration. The model used: A5M5N5B. The depth penetration of this electrode configuration is ca 3.75-6.25 m below terrain surface (after Slovak Technical norm No. 038 363). The measuring methodology is in accordance with STN 038 363 and STN 038 365.

Processing of the measured data

After termination of the field measurements, following data have been available for each measuring station:

- number of station
- average value of ΔV [mV] and its polarity in 20 m length for N-S and W-E directions
- average value of ρ_a [Ωm], calculated as an arithmetic average from ρ_a values, obtained for N-S and W-E courses.

From ΔV values, measured in both directions, the vector total has been constructed. The length of this vector (1 cm = 1 m) corresponds to ΔV value, originated by electric current flow at measuring station, while course of this vector represents direction of the current flow. The ΔV value, determined from a lenght of vector, corresponds to electrode distance of 20 m. Dividing this ΔV value by 20, the resulting ΔV value in $mV.m^{-1}$ has been obtained.

For determination of current flow density (I_f) in 1 m^2 space, it is necessary to know the ρ_a value of the rock medium, in which flow is passing. For calculation of the I_f [in $\mu A.m^{-2}$], the arithmetic average of both ρ_a values has been used.

Outputs of the observations and major results

The outputs of the above mentioned observations are as follows: Map of parameters of the natural and artificial current flows in surficial layer of the rock medium in 1:50 000 scale, Map of spatial distribution of the soil aggresivity degree on metal constructions after apparent resistivity values (Fig. 1) and Map of spatial distribution of the soil aggresivity degree after current flow density, both in 1:200 000 scale (Fig. 2). All maps have been constructed in accordance with STN 038 372 and STN 038 375.

After above mentioned norms, the relation between I_f, ρ_a and soil aggresivity degree is presented in Table 1.

Table 1.

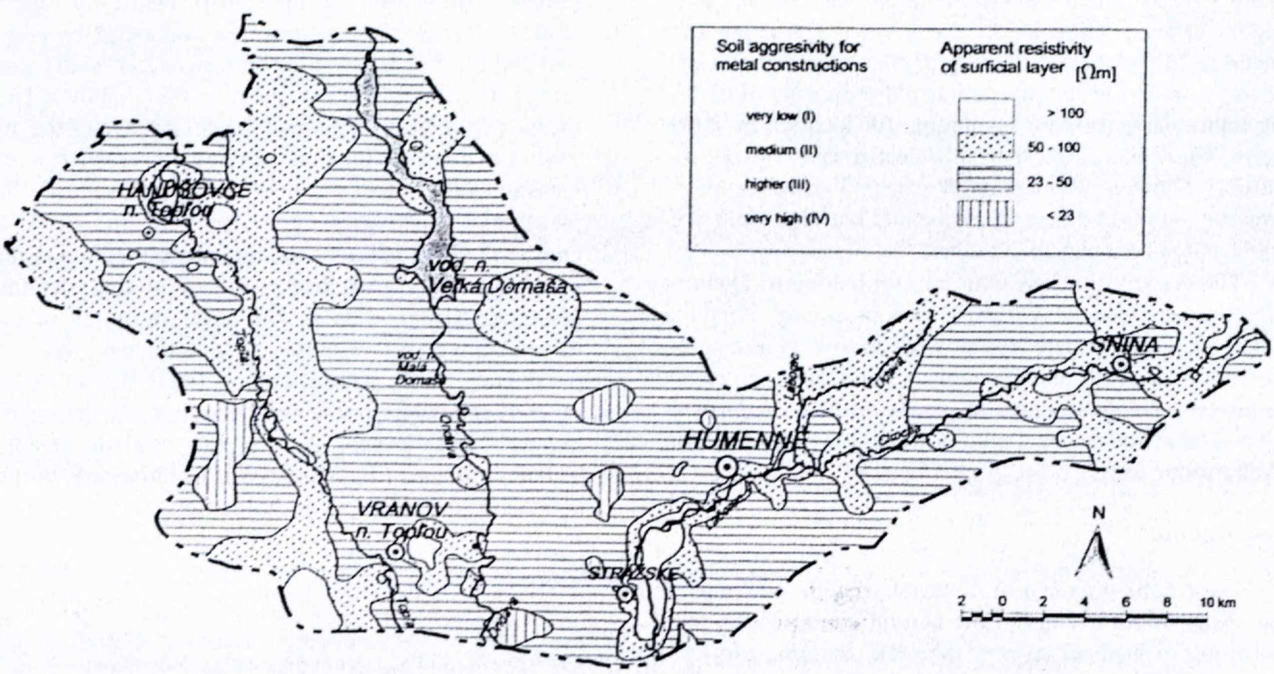
Soil aggresivity degree	ρ_a [Ωm]	I_f [$\mu A.m^{-2}$]
very low (I)	> 100	< 0.1
medium (I	50 – 100	0.1 – 3.0
higher (III)	23 – 50	3.0 – 100.0
very high (IV)	< 23	> 100

The results of the observations are as follows:

The Vranov-Humenné-Strážske region posseses-according to the spatial distribution of ρ_a values – all four degrees of the soil aggresivity. The medium and higher degrees prevail.

In case of presence of higher and very high aggesivity, it is necessary to protect metal underground constructions by anticorrosive measures and in case of metal pipe lines (for transport of gas and crude oil) by active cathode protection. The ρ_a values lower than 23 Ωm (very high soil aggresivity) have been detected in the area of Hlinné village (sw. part), north of Zámutov village (extremely sw. part), north of Lieskovec, at Topoľovka and at Nižný Hrabovec villages (s. margin of the region).

After values of current flow density (I_f) the medium aggresivity degree prevails in the area under study. This soil aggresivity does not need special anticorrosion and



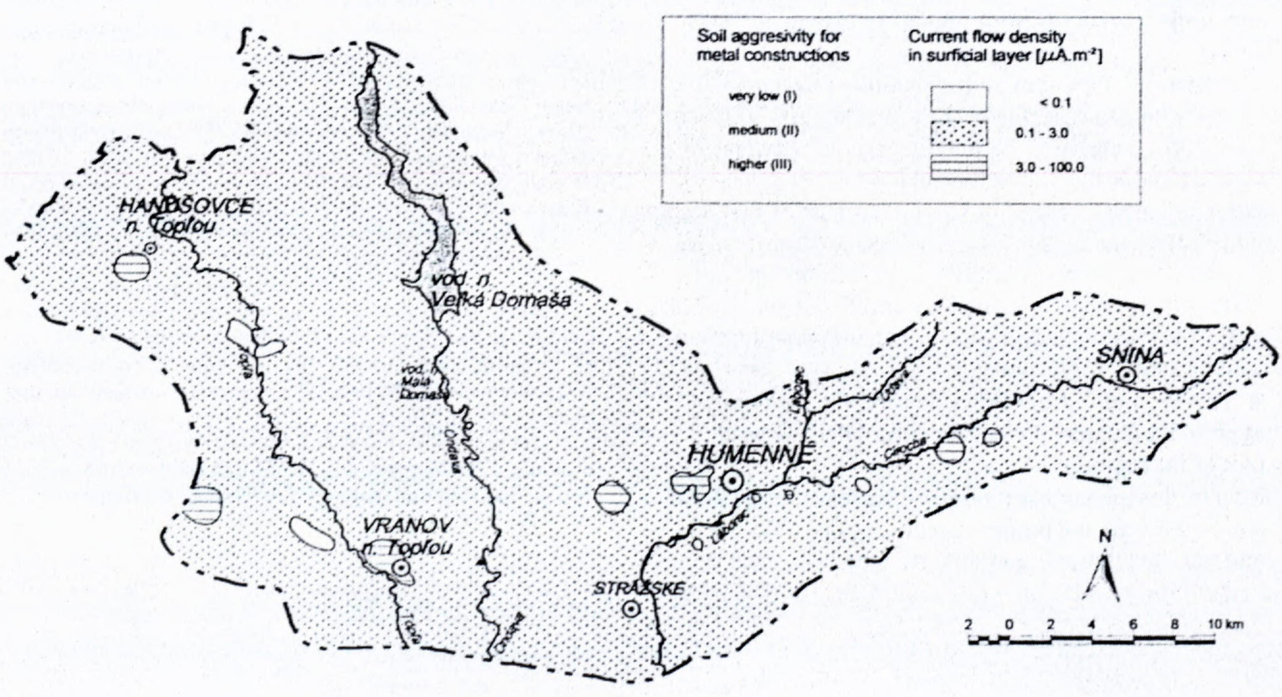


Fig. 2 *Fig. 1 Distribution of the soil aggresivity degree after current flowdensity values in Vranov – Humenné – Strážske region*

cathode protections of the metal constructions. The highest values of I_f have been observed along interrupted line of ca W-E direction, running through Zámutov-Vranov-Topoľovka-Humenné-Dlhé above Cirocha settlements. These high I_f values reflect a presence of the artificial electric current flows, caused by active cathode protection of the gas-pipe line.

Besides assessment of the soil aggresivity distribution, the schematic ρ_a map (Fig. 1) can be also utilized for other purposes. The places with ρ_a values higher than 100 Ωm represent occurrence of thicker layers of sands, gravely sands and gravels of the Quaternary as well as surficial layer of the sandstones, carbonates and solid neovolcanics in case of Quaternary cover absence. (The

Slovak Geol. Mag., 10, 3 (2004), 235 – 238

depth penetration of our observations was 3.75-6.25 m under surface.) These rocks are good construction raw materials. In places of terrain depressions along water flows, built by Quaternary permeable sediments (possessing high resistivity), are favourable for location of water wells. These places have been detected in following localities: Ďurďoš, Remeniny, Vechec, Vranov, east of Strážske, south and east of Humenné, between Belá and Snina and in area of Stakčín town.

The resistivities less than 23 Ωm belong to Quaternary loesses and clays with various sandy content, which increases resistivity, as well as to claystones interbedded by flysh and Paleogene sandstones, volcanic pelites and Neogene clays in places withou Quaternary cover.These rocks are favourable as raw material for brick production.

Conclusions

The results obtained in frame of solution of the project „Map of parameters of the natural and artificial current flows in surficial layer of the rock medium„ allow us to state following conclusions:

- Spatial presentation of the soil aggresity degree in the region under study can be used as a basis for planning the location of the underground metallic pipelines and other constructions and after site location for performing corrosion survey with higher density of measurements.
- Comparison of the spatial distribution of the resistivity values with geological map (Karoli et al., 2003) shows very good correlation between measured apparent resistivity and mapped lithological units.
- After resistivity values, in substantial part of the area under study the higher and very high soil aggressivity degree for various metallic constructions prevails. That is why these constructions need the protection against corrosion and in case of metallic pipe lines an active cathode protection.
- After values of current flows density, the medium soil aggresivity degree prevails in absolutely substantial part of the region.
- Map of the spatial distribution of the resistivity values can be utilized for proper location of the water wells and for location of quarries for gravely sands and gravels exploitation (in areas with resistivity higher than 100 Ωm). This statement is confirmed by comparison of the location of known water wells and gravel deposits in various parts of the Vranov – Humenné – Strážske region and the occurrence of the areas with highest resistivity values, observed by our measurements. Most of wells and deposits lie in the places with resistivities higher than 100 Ωm.

Due to the high value of the information obtained for planning the infrastructure and underground metallic constructions as well as for other purposes, mentioned above, we propose to compile the „Map of parameters of the natural and artificial current flows in surficial layer of the rock medium„ in frame of „Maps set of the geological factors of environment„ projects, financed by Ministry of Environment of the Slovak Republic, also in other regions of Slovakia.

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