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Revised position and age of the Eocene deposits on the northern slope of the Gorce Range (Bystrica Subunit, Magura Nappe, Polish Western Carpathians)

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Abstract: In the Bytrica Subunit of the Magura Nappe on the southern margin of the Mszana Dolna tectonic window new regional thrust-sheet located on the northern slope of the Gorce Range has been established. The Tobołów-Turbaczyk thrust sheet (TTT) is 25 km long and 3 to 5 km wide. This thrust-sheet is composed of the Lower to Middle/?Upper Eocene deposits which reveal facies connection both with the Bystrica and Krynica subunits. The TTT is characterized by a strongly tectonized 100-250 m thick sequence of the Lower to Middle Eocene basinal turbidites similar to those of the Zarzecze Fm. from the Krynica Subunit. It also cantains an extremely thick (up to 2250 m) complex of the Middle/? Upper Eocene chanel/lobe turbidite system similar to the Maszkowice Mb. of the Magura Sandstone Formation from the Bystrica Subunit. The TTT is wedged between Bytrica and Krynica subunits. The Maszkowice Mb. of TTT probably represents the deposits of the axial zone of the Middle Eocene Magura sandstone fan.

Key words: lithostratigraphy, foraminifera, calcareous nannoplankton, Eocene, Tobołów-Turbaczyk thrust sheet, Bystrica Subunit, Magura Nappe, Western Carpathians.

Introduction

The characteristic feature of the middle part of the Magura Nappe in the Polish Outer Carpathians is an occurrence of the Mszana Dolna tectonic window (MDW). The central and most uplifted part of this window is dominated by the Oligocene Krosno Formation of the Dukla Unit (Żytko et al., 1989), whereas the narrow, marginal part of it is occupied by the Cretaceous-Oligocene deposits of the Grybów Unit (Fig. 1). The area of MDW and its surroundings were the subject of fundamental geological investigations (see Burtan et al., 1978 a, b; Mastella, 1988). Well exposed deposits of the Magura Nappe belong to the Rača and Bystrica subunits. According to the detailed geological map of the Mszana Dolna sheet (Burtan et al., 1978 a) the southern margin of MDW is build up of the Cretaceous-Paleogene deposits of the so called "south peri-window" zone, which could be correlated with the Bystrica Subunit (Fig. 2). Three thrust-sheets were distinguished by mentioned authors in this zone. From north to south there are: the Poręba Wielka, Koninki-Jasień-Kustrzyca and Szumiąca-Frączkowa-Lubomierz. The first two trust-sheets are exclusively built up of the Cretaceous-Paleocene deposits and have only local significance, whereas the third one is composed of the Cretaceous-Eocene deposits and is of regional importance.

For the last few years, the southern margin of the MDW has been the subject of geological investigations of the first author and his students, during the courses of geological mapping. The biostratigraphical studies have been carried out by the other authors. These studies enable us to recognize better the stratigraphy of the N slope of the Gorce Range and to provide a new structural interpretation of the Bystrica Subunit in this area. The aim of this work is to determine the litho- and biostratiraphy of the Eocene deposits, explain the structural pecularities of the Bystrica Subunit in the Gorce Range, and to show paleogeographical implications of our findings.

Lithostratigraphy

In the Magura Nappe three turbidite complexes are distinguished: Campanian / Maastrichtian-Paleocene, Lower-Upper Eocene and Upper Eocene-Lower Miocene (Oszczypko, 1992; 1998). Each complex begins with variegated shales and passes upwards into basinal turbidites, then into chanel-lobe, thick-bedded turbidites and finally into basinal turbidites. These complexes represent stratigraphic sequences and the groups of formations in the lithostratigraphic sence. In the investigated area only two first turbidite complexes have been recognized that belong to the Grajcarek (Albian-Paleocene) and Beskid (Lower-Upper Eocene) groups (see Birkenmajer & Oszczypko, 1989; Oszczypko, 1991).

Grajcarek Group

The Upper Cretaceous-Paleocene strata occur between Olszówka and Lubomierz (Fig. 2; see also Burtan et al. 1978 a). The formal and informal lithostratigraphic units are used in parallel for these deposits. The oldest strata

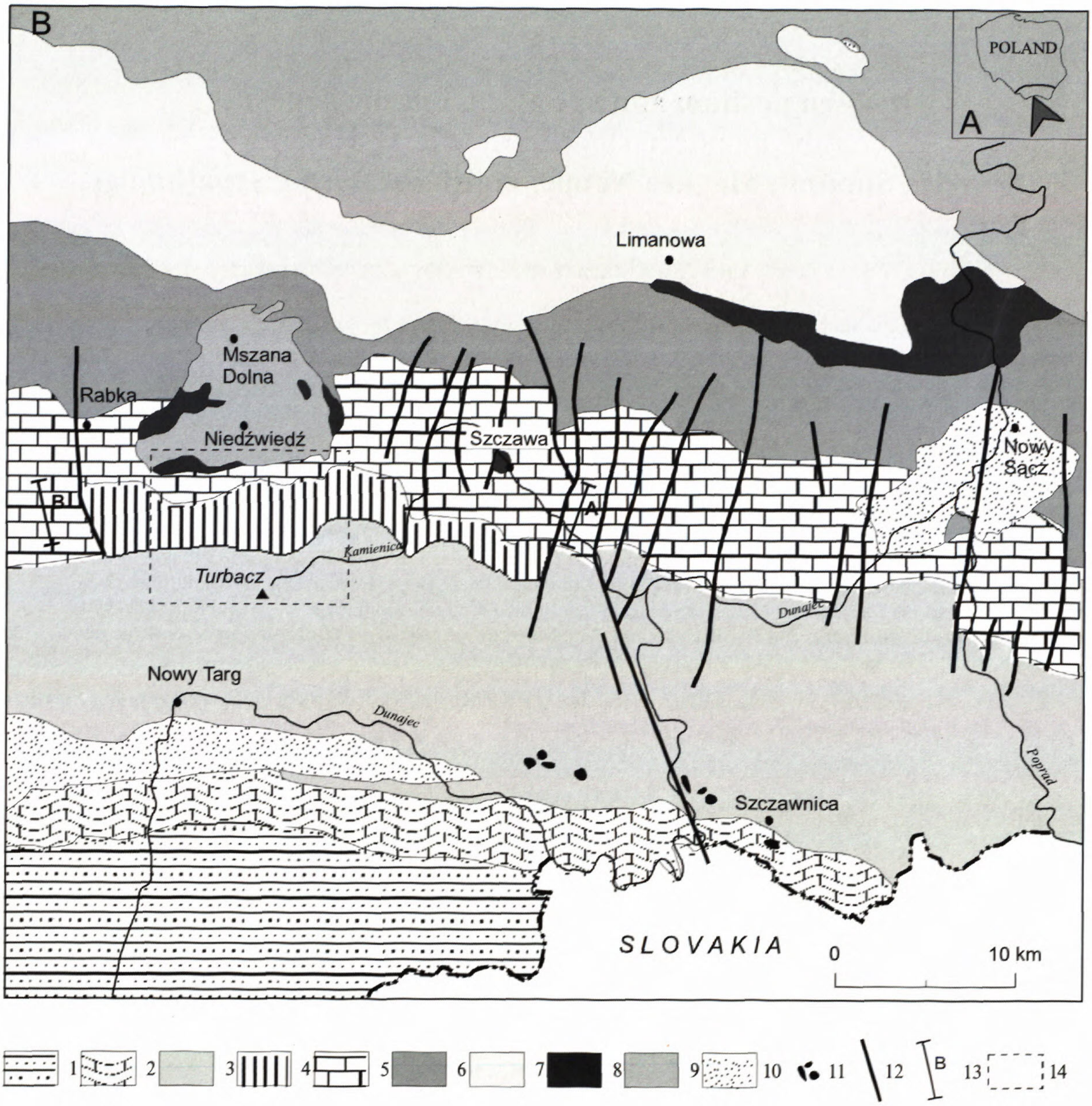

Fig. 1. A-Position of the investigated area. B-Sketch-map of the middle part of the Polish Carpathians. 1-Podhale Flysch, 2-Pieniny Klippen Belt; Magura Nappe: 3-Krynica Subunit, 4-Tobołów-Turbaczyk thrust sheet, 5-Bystrica Subunit, 6-Raca Subunit, 7-Siary Subunit, 8-Grybów Unit, 8-Dukla Unit, Silesian & Sub-Silesian units, 9-Miocene onto the Carpathians, 10-Miocene andesites, 11-Chabówka (B) and Zbludza (A) sections, 12-study area.

(Albian ?-Cenomanian), represented by spotty shales (Hulina Fm.), are exposed only on the slumped bank of the Koninki Stream (Fig. 2, see also Burtan et al., 1978 a, b; Birkenmajer & Oszczypko, 1989). The Turonian-Senonian variegated shales of the Malinowa Fm. usually form the base of the Magura Nappe sequence (Birkenmajer & Oszczypko, 1989; Malata & Oszczypko, 1990). The Senonian-Paleocene turbidite deposits overlying the Malinowa Fm. and followed by the Lower Eocene variegated shales (Łabowa Fm.) are traditionally referred as the so called "Inoceramian beds", though the name Ropianka Beds has also been used. Within these deposits there are several lithostratigraphic units of a lower rank (Fig. 3). There are: Hałuszowa Fm. (Birkenmajer & Oszczypko, 1989; Malata & Oszczypko, 1990), Kanina beds (Burtan et al., 1978 a, b; Oszczypko et al., 1991), Jaworzynka beds (Burtan et al., 1978 b), Szczawina Sandstone (Sikora & Żytko, 1959; Oszczypko et al., 1991) and the Ropianka beds. In the Olszówka-Lubomierz area these deposits are 200-250 m thick and can be subdivided into three members. The lower member (Kanina beds, Campanian) is composed of thin-bedded turbidites with intercalations of turbidite limestones (Cieszkowski et al. 1989). These deposits are followed by the thick-bedded sandstones and granule conglomerates of the Szczawina Ss. (?Maastrichtian-Paleocene, see Malata et al., 1996). The uppermost member belongs to the Ropianka beds (Paleocene) and is composed of thin-

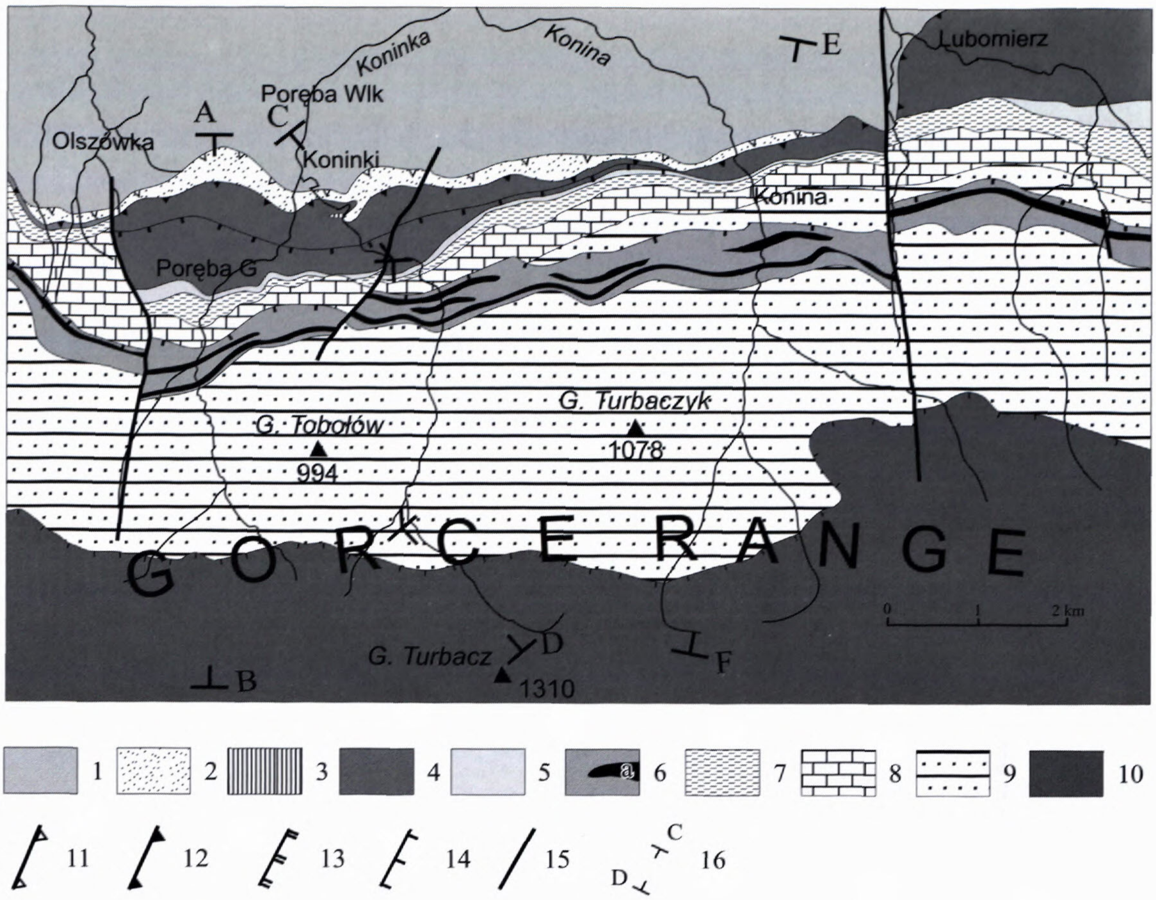

Fig. 2. Geological map of the Magura Nappe on the southern margin of Mszana Dolna tectonic window (Lubomierz area partly after Cabaj, 1993, simplified). 1-Oligocene Krosno beds of Dukla Unit, 2-Grybów Unit, (3-9) Magura Nappe - Bystrica Subunit: 3-Albian-Cenomanian deposits, 4-Cenomanian-Paleocene; Eocene: 5-Łabowa Fm., 6- Zarzecze Fm., a-variegated shales, 7-Beloveza Fm., 8- Bystrica and Żeleźnikowa fms., 9-Maszkowice Mb. of the Magura Fm., 10-Krynica Subunit, 11-Grybów overthrust, 12-Magura overthrust, 13-Bystrica Subunit internal overthrusts, 14-Krynica overthrust, 15-faults, 16-cross-sections.

bedded turbidites with thin intercalations of variegated shales. The Senonian-Paleocene sequence of the Bystrica Subunit reflects global sea-level fluctuations from the Turonian HST through Maastrichtian-Paleocene LST to Early Eocene HTS (see Haq et al, 1987).

Beskid Group

According to earlier publications (see Burtan et al., 1978 b), on the northern slope of the Gorce Range the Eocene deposits of the Bystrica Subunit form the continuous sequence incorporated into the Szumiąca-Frączkowa-Lubomierz thrust sheet. However, the results of our investigations of the Eocene deposits show the presence of two sequences more or less the same in age. Based on this fact it has been possible to establish two new thrust-sheets: the Konina-Lubomierz (N) and Tobołów-Turbaczyk (S). Lithostratigraphy of these sequences are described separately.

Konina - Lubomierz sequence

Łabowa Shale Formation. Deposits belonging to the Łabowa Sh. Fm. (Oszczypko, 1991) occur in a narrow belt between Olszówka and Lubomierz (Fig. 2). The lower boundary of this formation is tectonic in some places. The best exposures are known from the Lubomierz and Poręba Górna sections (Fig. 3). The lowermost portion of the formation is represented by a few metres of red shales passing upwards into very thin-bedded turbidites. The turbidite sequence usually begins with thin-bedded (1-6 cm), very fine-grained (Tc), green, carbonate-free sandstones passing up to a few centimetres of the green shales, and finally to a few centimetres of red shales. The shales are mainly soft and carbonate-free. The green or blue shales with intercalations of thin-bedded sandstones are observed less frequently. In the Poręba Górna section the lowermost part of this formation contains one or two layers of thick-bedded sandstones (up to 2 m) and intercalations of grey marls. The thickest sandstone bed reveals paleotransport from ESE. The thickness of the formation attains up to 50 m.

Beloveža Formation. This formation is dominated by thin to medium-bedded turbidites (Tc+conv. and Tcd). Shales, varying in colour (green, grey, blue, brown and yellowish), distinctly prevail over sandstones. In the basal part of the formation there occur sequences of alternating

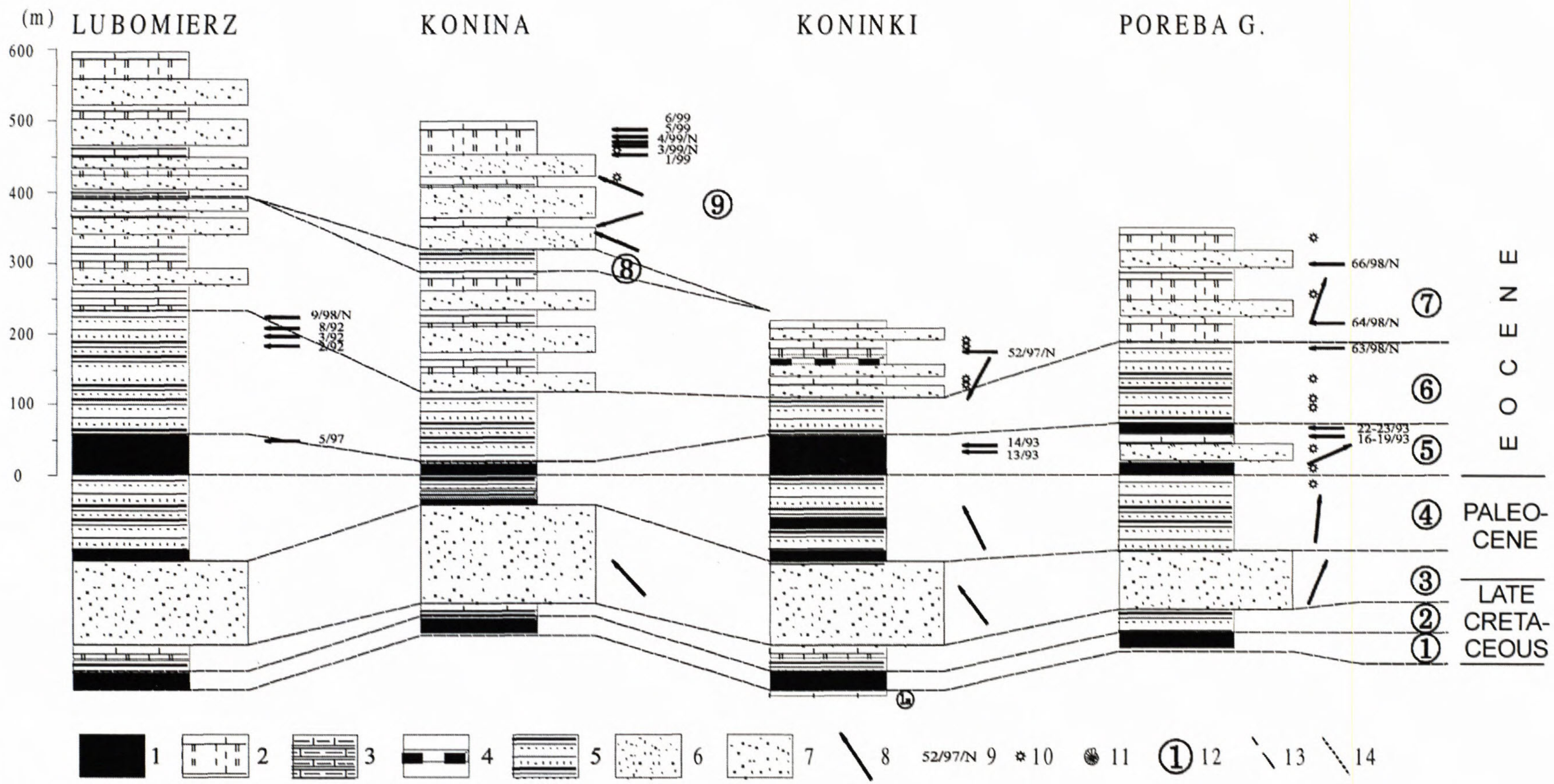

Fig. 3. *Lithostratigraphic section of the Konina-Lubomierz sequence of the Bystrica. 1-red shales, 2-turbidite limestones, 3-turbidite marls, 4-hornstones, 5-thin to medium-bedded turbidites, 6-thick-bedded turbidites, 7-thick bedded sandstones and conglomerates, 8-paleotransport direction, 9-numbers of samples, 10-barren samples, 11- Reticulophragmium amplectens (Grzybowski), 12-litostratigraphic units, 13-TTT sole thrust, 14-faults. Litostratigraphic units: (1-11) Bystrica sububit: 1a- Hulina Fm., 1-Malinowa Sh. Fm. and Haluszowa Fm., 2-Kanina beds, 3-Szczawina Ss., 4-Ropianka beds, 5-Łabowa Sh. Formation, 6-Beloveža Formation, 7-Bystrica Fm., 8 -Żeleźnikowa Fm., 9-Maszkowice Mb.of the Magura Fm., 10-Mniszek Sh. Mb., 11-Poprad Ss. Mb., TTT: 12-Zarzecze FM., 13-Maszkowice Mb.*

layers of different coloured shales. Yellowish and brown shales are usually calcareous, while the green ones are, as a rule, carbonate-free. The accompanying muscovite sandstones are very fine-grained and thin-bedded (5-12 cm). The medium-bedded T_{bc} sandstones (20-40 cm) appear less frequently. The thickness of the Beloveža Fm. reaches 50 to 120 m (Fig. 3).

The *Beloveža* Fm. of the Konina – Lubomierz sequence could be regarded as an equivalent of the Vychylovka Fm. described from the northern Orava (Potfaj, 1989).

Bystrica Formation. Outcrops of the Bystrica Fm. (see Oszczypko, 1991) are very easily visible in morphology, forming a W-E trending belt of round-off hills. In other papers (see Burtan et al., 1978 a, b) this formation was described as the "Łącko beds". It comprises thick -bedded sandstones with intercalations of the Łącko marls. The sandstones, 80-200 cm thick, are massive, medium to coarse-grained, glauconite/muscovitic with carbonate-free cement. The flute-casts reveal paleotransport from SW. The sandstone layers pass into massive marls, sometimes silicified, brown or blue-to-grey and whitish where weathered. The thickness of the individual beds of the Łącko marls ranges from 2 to 5 m. In the Koninki section (Figs. 2, 3) the marls contain 1-20 cm intercalations of black hornstones. The thickness of the formation is up to 150 m (Fig. 3).

Żeleźnikowa Formation. Equivalents of the Żeleźnikowa Fm. (Oszczypko, 1991) have been found in a few stream sections on the east of the Koninki Stream. As a rule, these deposits occur at the top of the Bystrica Fm. and at the base of the Maszkowice Mb. They are composed of the thin to medium-bedded turbidites of the Beloveža lithofacies with numerous intercalation of the Łącko marls. The thickness of the formation is up to 50 metres (Fig. 3).

Maszkowice Member of the Magura Formation. The Maszkowice Mb. (Oszczypko, 1991) is exposed only in the Lubomierz and Konina sections (Fig. 2, 3). In other interpretations (see Burtan et al., 1987), these beds were also covered by the term "Łącko beds". The best exposures are located in the Konina section. This member is represented by the thick and medium-bedded muscovite sandstones with infrequent intercalations of the Łącko marls. The sandstones are 40-200 cm thick, medium to coarse grained, muscovitic with illite-carbonate cement. They are massive, sometimes amalgamated and often contain muddy intraclasts and coalified flakes in the upper portion of the beds. The intercalations of the Łącko marls range from 80 to 200 cm in a thickness. The marls are greyish and whitish where weathered. In the Konina section the thick-bedded sandstone and marl complex is followed by a 60-100 metres sequence of thin to medium-bedded sandstone/marly turbidites. The tectonically reduced thickness of the Maszkowice Mb. is up to 200 m. The flute casts reveal paleotransport from SE (Fig. 3).

The Maszkowice Mb. of the Magura Fm. is an equivalent of the Kycera Mb. of the Zlin Fm. described from the northern Orava (Pivko, 1998).

Tobołów-Turbaczyk sequence

Zarzecze Formation. The term "Zarzecze beds" was introduced by Oszczypko (1979) for the flysch strata in the Krynica Subunit previously distinguished as the "Beloveža beds", "hieroglyphic beds" or "sub-Magura beds". Ten years later the Zarzecze Fm. was established as a formal lithostratigraphic unit in the Krynica Subunit (Birkenmajer & Oszczypko, 1989; Oszczypko et al., 1990). In this paper we propose to distinguish this formation in the southern part of the Bystrica Subunit, previously known as "hieroglyphic beds" sensu Burtan et al. (1978 a, b). Our investigations have documented that the lower boundary of the Zarzecze Fm. ("hieroglyphic beds") is tectonic what contradicts the previous opinion of Burtan et al. (1978 b) who considered this boundary as stratigraphic. This strongly deformed formation reveals the numerous, small, imbricated folds and trust sheets. The upper boundary of the formation is represented by the gradual transition to the Magura Fm. In the all sections (Fig. 4) the Zarzecze Fm. is dominated by the very thin-bedded basinal turbidites (Fig. 5). These deposits are formed by blue-greyish shales with subordinate intercalations of very thin (1-5 cm), fine grained, ripple-cross laminated, calcareous sandstones (Tc). The shales where weathered, reveal the alternating yellow and green "zebra" like sequences. The thin (1-2 cm) yellow shales are usually calcareous and rich in *Nereites irregularis* (Schafthautl) known also as *Helminthoidea irregularis* (see Uchman,1998), whereas the olive-green shales up to 10 cm thick are bioturbated and calcereous-free. In the lower and upper part of the sections, thin (1-5 cm) intercalations of the cherry-reddish shales are observed. In the Poręba stream the lower horizon of the red shales joins from the south with a complex of thin to medium-bedded turbidites, about 100 m thick. This overturned sequence is dominated by blue-greyish, fairly calcareous mudstones and sandstones with a few intercalations of turbidite limestones. These deposits are very rich in trace-fossils with dominating *Noviculichnum marginatum* Książkiewicz (Fig. 6) and *Scolicia plana* Książkiewicz (see Uchman, 1998). Higher in the section, in normal position once more, appear the "zebra" like turbidites with a few thin layers of red shales. The last portion of the Zarzecze Fm. in the Poręba section is characterized by a 10-15 m thickening-upward sequence followed by the first layer of the thick-bedded sandstones, which marks the lower boundary of the Magura Fm.. In the Koninki section in the middle part of the Zarzecze Fm., a complex of at least 10 metres of the medium to thick-bedded strata resembling the Paleocene/Lower Eocene Szczawnica Fm. from the Krynica Subunit (Birkenmajer & Oszczypko, Oszczypko et al., 1990) has been noticed. It is followed by a set, a few metres thick, of the very thin-bedded turbidites with thin intercalations of red shales and then by a few metres of the zebra-like yellow-green shales. The upper portion of the formation is represented by 20-25 m of thickening-upward turbidite sequence terminated by the first thick-bedded sandstone of the Magura Fm. A similar sequence with the overturned middle portion of the Zarzecze Fm.

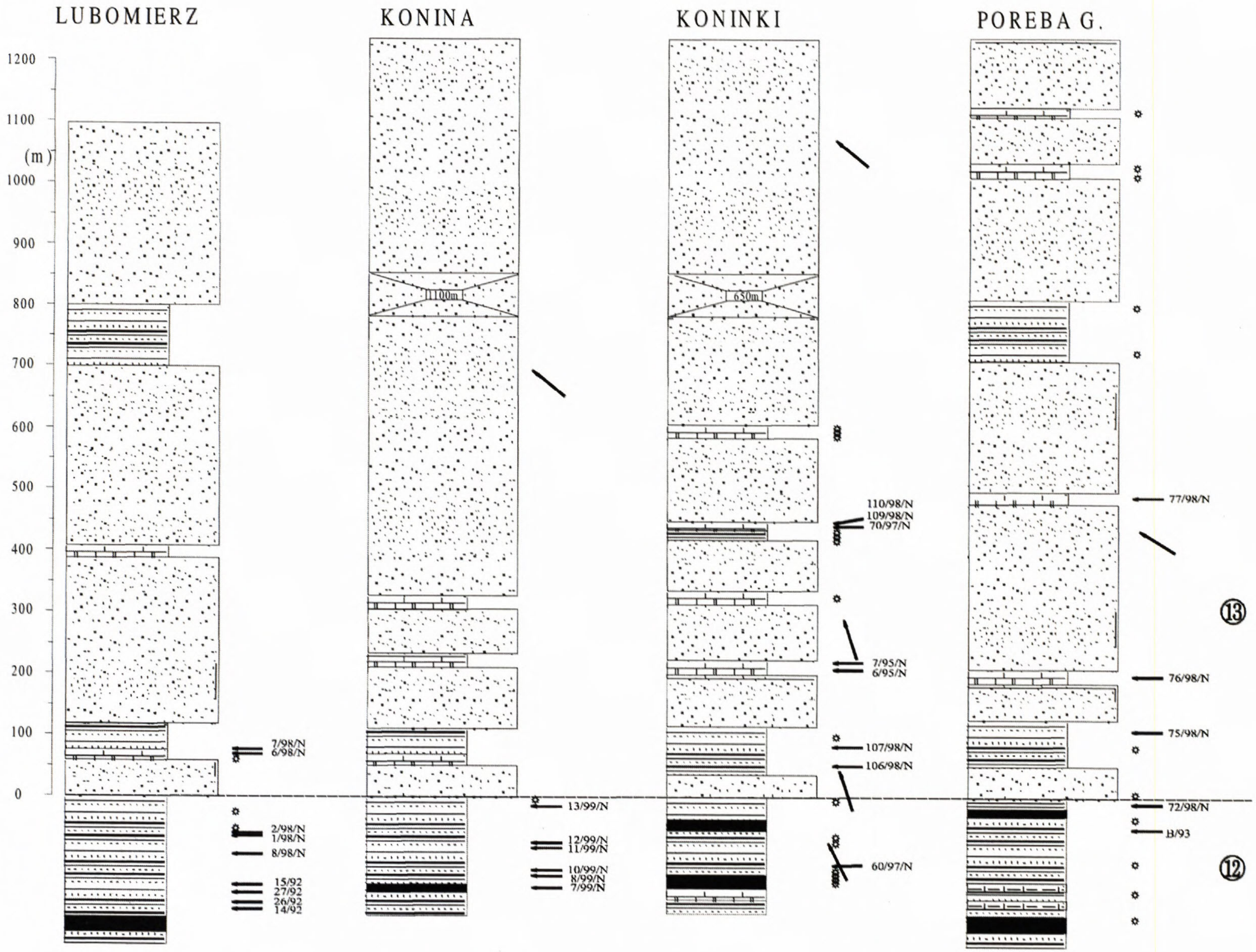

Fig. 4. Lithostratigraphic section of the Tobołów-Turbaczyk sequence of the Bystrica Subunit. For explanations see Fig. 3.

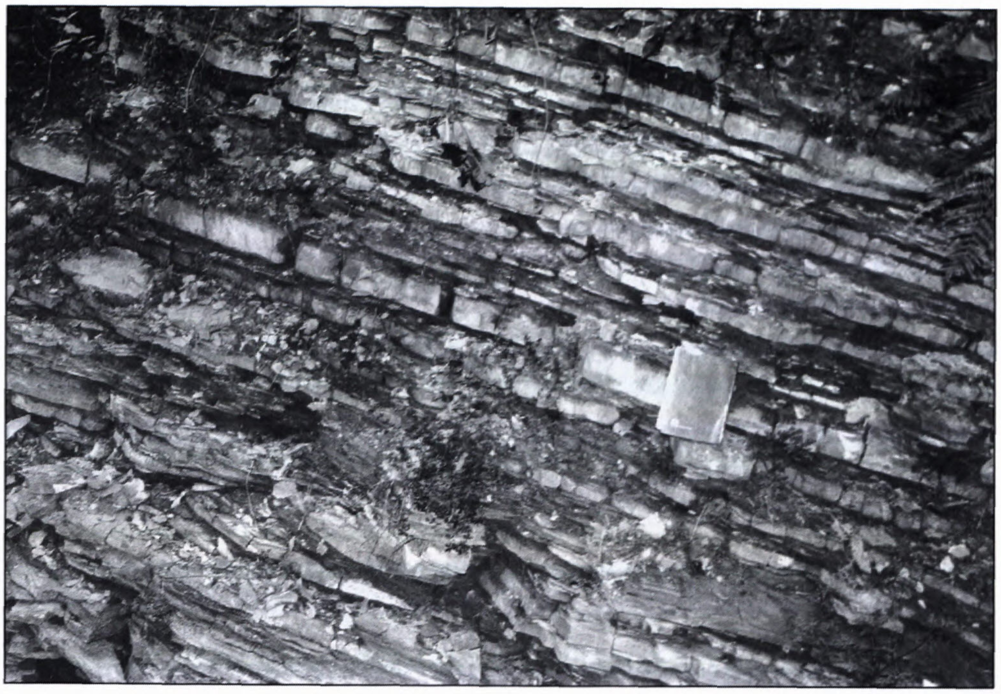

Fig. 5 . Thin-bedded turbidites of the Zarzecze Fm. of TTT in the Poręba Stream.

Fig. 6. Noviculichnium marginatum KSIĄŻKIEWICZ. *Zarzecze Fm. of TTT in the Poręba Stream.*

has been observed in the Konina section. The thickness of the Zarzecze Fm. could be roughly estimated as being between 100 and 200 m metres (Fig. 4). The flute cast measurements indicate paleotransport direction from SW in the lower to SE in the upper part of the formation.

Maszkowice Member of the Magura Formation. On the geological map of Burtan et al. (1978 a) the Maszkowice Mb. was distinguished as the "Magura beds" of the south "peri-window" facial zone. Its age was considered as the Late Eocene by the comparison with the Magura beds in the Babia Góra area. The Maszkowice Mb. can be traced in a belt a few kilometres wide, which is very well pronounced in morphology of the Gorce Range. This belt is dominated by a few mounts up to 1078 m asl high (Brody – 940 m, Tobołów – 994 m, Turbaczyk – 1078 m, and Kiełbasna – 950 m). From the south the Maszkowice Mb. is limited by the overthrust of the Krynica Subunit (Fig. 2).

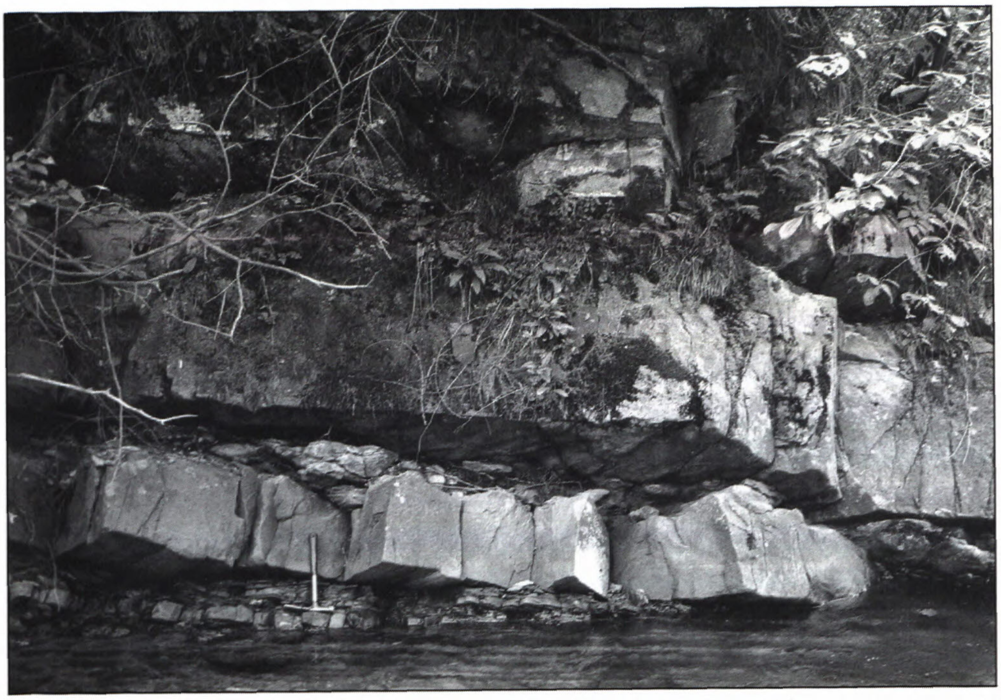

Fig. 7. Base of the Maszkowice Mb. of the Magura Fm. of TTT in the Koninki Stream.

The northern edge of the Gorce Range, at the altitude of 700-750 m asl, is built up by the lower part of the member up to 150 m thick. This portion of the Magura Fm. was described by Burtan et al. (1978 a) as the "sub-Magura beds". The base of the formation is composed of a few layers of thick-bedded (up to 250 cm) sandstones (Figs. 4, 7). They are massive, sometimes amalgamated, greyish in colour, fine to medium-grained and usually slightly carbonate. In the lowermost portion of the formation the middle-bedded (40 cm) slumped sandstones have been observed in the Poręba i Koniny sections. The imbricated slump folds reveal the paleotransport from SE (150-160°), whereas the big flute casts indicate paleotransport from ESE (110-120°). Higher up in the section, 15-20 m thick assemblage of thin to medium-bedded (up to 2-20 cm) turbidites occur, resembling the upper portion of the Zarzecze Fm. They also contain 5-6 m thick set of the thick-bedded sandstones. The thin-bedded turbidites are accompanied by rare intercalations of dark-greyish marls of the Łącko type and thin layers of turbidite limestones.

Above the "sub-Magura beds" the thick-bedded (80-150 cm) and sometimes very thick-bedded amalgamated sandstones dominate. The thick-bedded sandstones usually occur in a few metre to several metre assemblages, whereas individual sandstone beds are separated by blue-greyish mudstones rich in the coalified flakes and pyrite, rusty where weathered. The thick-bedded sandstones are intercalated by thin to medium-bedded turbidites of a few metres, which contain 0,8 to 6 m layers of the dark marls. In comparison with typical Łącko marls those in question are more hard and partly silicified.

The thick layer of the thin-bedded flysch up to 150 m has been recognized in the Poręba Górna section about 700 m above the base of the Magura Fm. (Fig. 4). They are dark-greyish, fine-grained, cross-laminated and/or convoluted calcareous sandstones accompanied by strongly bioturbated, yellow, calcareous mudstones and dark green calcareous-free shales.

The uppermost portion of the Maszkowice Mb. is dominated by the thick-bedded sandstones, pebbly sandstones and granule conglomerates with rare mudstone/shale intercalations. The thickness of the Maszkowice Mb. increases from 1200 m in the Poręba Wielka section to 1800 m in the Koninki section and finally up to 2250 m in the Konina section (Fig. 4). The flute cast measurements indicate paleotransport from the east-south-east (90-120°).

As it has already been mentioned, the Maszkowice Mb. of the Magura Fm. is an equivalent of the Kycera Mb. of the Zlin Fm. described from the northern Orava (Pivko, 1998).

Krynica sequence

The southern periphery of the investigated area belongs to the Krynica Subunit, which build up the higher part of the Gorce Range. The frontal part of this subunit is composed of the Szczawnica, Zarzecze and Magura formations (Fig. 2). The Szczawnica Fm. (Paleocene/ Lower Eocene) is represented by the thin to medium-bedded flysch consisting of calcareous sandstones alternating with carbonate-free or slightly calcareous shales, grey, bluish or black (see Birkenmajer & Oszczypko, 1989). This formation is followed by thin-bedded turbidites of the Zarzecze Fm. (Lower Eocene) with intercalations of thick-bedded sandstones and conglomerates of the Krynica Mb. The youngest deposits of this sequence are developed as the thick-bedded sandstones and represent the Piwniczna Mb of the Magura Fm. (Lower/Middle Eocene, Birkenmajer & Oszczypko, 1989). This member is an equivalent of the Magura Sandstones in the Orava region (Potfaj, 1983)

Biostratigraphy

For the purpose of this paper small foraminifera and nannoplankton studies have been carried out by the second and the third author respectively. More than 30 foraminiferal and 80 samples for nannoplankton research were collected from the Łabowa Shale Fm., Beloveza Fm, Maszkowice Mb. of the Konina-Lubomierz sequence and from the Zarzecze Fm. and Maszkowice Mb. of the Tobołów-Turbaczyk sequence. The position of the samples against litological logs are presented in Figs. 3, 4. Distribution of the foraminifera and calcareous nannoplankton from the selected samples is presented in the Tabs. 1-2.

All samples for nannoplankton studies were prepared with the standard smear slide technique for light microscope (LM) observations. The investigations were carried out under LM at a magnification of 1024x and 1600x using phase contrast and crossed nicols. Several specimens photographed under LM are illustrated in Fig. 8.
It should be noticed that investigated litological units are generally poor both in foraminifera and calcareous nannoplankton. Most of the samples needed very thorough examination to find any microfossils.

Foraminiferal assemblages

Konina – Lubomierz sequence

Łabowa Sh. Fm. Foraminiferal assemblages of this unit display rather low diversity and consist of entirely agglutinated taxa (Tab. 1). Among tubular forms *Nothia excelsa* (GRZYBOWSKI) is the commonest. Very characteristic assemblage has been found in sample 23/93 in the Poręba Górna section (Fig. 3, Tab.1). *Glomospira choroides* (JONES et PARKER) and *G. gordialis* (JONES et PARKER) significantly outnumber the other taxa. This assemblage correlates well with the Early Eocene *Glomospira* acme zone distinguished in the Outer Carpathians (Olszewska, 1997) and also known of in other places (Kaminski et al., 1996). The second type of an Early Eocene assemblage contains quite numerous specimens of *Paratrochamminoides* and *Trochamminoides* beside numerous *Glomospira.* The samples 22/93 (Poręba Górna) and 5/97 (Lubomierz) are examples of the latter. In other samples, though assemblages are impoverished, the mention taxa are relatively dominant so, they can be roughly attributed to the same age (Fig. 3: s. 14/93 - Koninki;16/93, 17/93, 19/93 - Poręba Górna).

Beloveža Fm. Foraminiferal taxa are neither diverse nor numerous. Assemblages are dominated by agglutinated forms. Calcareous specimens have also been found though their poor preservation makes it difficult to identify species and sometimes even genera. Among agglutinated specimens an appearance of *Haplophragmoides walteri* (GRZYBOWSKI) seems to be characteristic. The other species are similar to those in the previous unit though they are much less frequent. Calcareous benthonic forams such as *Nuttallides trumpyi* (NUTTALL) and specimens which are most likely to be representing the family *Nodosaridae* are stable and relatively common element of the foraminiferal fauna. In the upper part of this unit in the Lubomierz section (s. 8/92) piritized forms of *Chilostomella* have also been found. They are represented by the largest population among other taxa (Tab. 1). Rare specimens of the planktonic forms are also present though their species assignment has been impossible. Almost identical microfauna has been noticed in the Beloveža Fm. in the Uhryń Stream. The piritized forms of *Chilostomella* were commonly noticed in deposits of the Magura Unit regarded as the upper part of the Eocene in age (Jednorowska, 1968; Malata, 1981). The most common species, known from the Outer Carpathians, *Ch. chilostomelloides* VASIČEK according to Olszewska has its range from the upper Middle Eocene to Late Eocene (Olszewska et.al., 1996). Recent investigations carried out in the described area as well as in the vicinity of Krynica (Oszczypko et. al., 1999) have shown that the assemblages with piritized *Chilostomella* can also appear slightly earlier than it has been thought. Significant presence of *Nuttallides trumpyi* in the described assemblages cannot determine the age as this species is a common element of the Paleocene and Eocene deep water assemblages (Tjalsma & Lohmann, 1983). Described foraminiferal assemblages from the Beloveža Fm. occur above the Early Eocene *Glomospira* acme zone and most probably represent Middle Eocene.

Maszkowice Mb. In the lower part of the Konina section the assemblages are not very rich but dominated by agglutinated taxa. The presence of planktonic species *Acarinina bulbrooki* (BOLLI) and *Subbotina eoceana* (Gumbel) in sample 1/99 indicates the Middle Eocene age (Toumarkine & Luterbacher, 1985; Olszewska et al., 1996). The specimens identified as *Ammodiscus* cf. *latus* Grzybowski in sample 4/99 points to the upper Middle Eocene (Geroch & Nowak, 1984). The highest sample in the section 6/99 is characterised by very abundant piritized *Chilostomella* and quite numerous specimens of the family *Nodosaridae*. Thus, Maszkowice Mb. in the Konina section is not older than upper Middle Eocene.

Tobołów-Turbaczyk sequence

Zarzecze Fm. Foraminiferal samples of this formation were collected in the Konina, Poręba Górna and Lubomierz sections of the Turbaczyk-Tobołów sequence (Fig. 4). Agglutinated foraminifera are dominant group in the assemblages. They are moderately numerous but all together do not have a very specific character. Sample 7/99 shows some affinities with the assemblages of the Early Eocene *Glomospira* zone. The samples 8/99 and B-93 contain *Haplophragmoides walteri* (GRZYBOWSKI), *Gero-*

chammina conversa (GRZYBOWSKI), *Paratrochamminoides* div.sp. in similar amount, suggesting also some analogy to the microfauna known from the lower part of the Eocene (Kaminski et. al., 1996). *Subbotina linaperta* (FINLAY) found in sample 8/99 is rather long-ranging species known from the Paleocene and Eocene (Olszewska et. al., 1996). In sample 14/99 the presence of very small and piritized forms of *Chilostomella* and other benthonic forms is worth mentioning. The precise age determination based on described foraminifera is rather difficult. The assemblages are Eocene in age and are most likely to represent Early - Middle Eocene.

Tab. 1. Distribution of the foraminiferal taxa in the selected samples.A – abundant not counted.

	ŁABOWA FM.				BELOVEZA FM.			ZARZECZE FM.				MASZKOWICE MB.				
	17/ 93	22/ 93	23/ 93	5/ 97	2/ 93	3/ 93	8/ 92	7/ 99	8/ 99	14/ 99	B/ 93	1/ 99	4/ 99	5/ 99	6/ 99	7/ 95
Agglutinated foraminifera																
Bathysiphon sp.	3				5		11		10	20		5	A	20	10	1
Nothia excelsa	24	A	A	> 20			8	A	10	4	26	3		12	11	
Rhizammina sp.							2									
Rhabdammina cylindrica	1								15							11
Psammosphaera sp.						1		3					3			1
Saccammina cf. grzybowskii				5			5									
Saccammina sp.									8		6		2			
Ammodiscus cf. demarginatus									3		3					
Ammodiscus cf. latus													2			
Ammodiscus sp.	1				4				1							
Glomospira charoides	}16	}100	}100	70	2	1		4	3		15				2	
Glomospira gordialis					4	3	8	16	6		9	1	2		2	1
Glomospira glomerata		10		3												
Glomospira irregularis	2	2	4			1		2								
Glomospira serpens		6						1							1	
Reophax sp.				2						1						
Subreophax guttifer								1	2				1			
Subreophax scalaris		3										1				
Subreophax splendidus				4					1						1	
Haplophragmoides horridus								1				1				
Haplophragmoides cf. *kirki*			3													
Haplophragmoides walteri					10	3	7		18		27					
Haplophragmoides sp.	7	2		1	8		1	13		10			15		17	3
Paratrochamminoides spp.	15	80	10	32	3	2		20	15	4	20		2	2	5	
Trochamminoides spp.		3	2	17	1	1	1		7		10					
Ammosph. Pseudopauciloculata			2				2		2			1				
Recurvoides spp.	3	26	16	4	2	8	18	10	13	1	6		2	2		5
Spiroplectammina spectabilis																2
Trochammina sp.					3		6		20	8					4	
Gerochammina conversa		3			2		3		14		15	10	2		5	1
Karrerulina cf. *coniformis*										1	3					
Karrerulina horrida		2														
Karrerulina sp.																
Arenobulimina sp.											2					1
Calc. benthonic foraminifera																
Nodosaria longiscata															10	
Nodosaria sp.					1		1									
Nodosaridae indet.					16	2	5					1	6		30	3
Fissurina sp.							1									
Bulimina sp.														2		
Globobulimina sp.										2				1		
Fursenkoinidae indet.										10						
Cibicidoides sp.							1									
Nuttallides trumpyi					7	3	8						2		11	1
Asterigerina sp.														1		
Chilostomella spp.							28			21			7	12	50	
Anomalinoides sp.															1	
Gyroidinoides sp.															1	
Benthonics indet.									3	6	5					
Planktonic foraminifera																
Acarinina bulbrooki												1				
Acarinina rotundimarginata																1
Acarinina sp.							1									
Turborotalia cf. *cerroazulensis*																1
Globorotaloides suteri															1	
Subbotina linaperta									1							
Globigerina cf. *corpulenta*																1
Globigerina eoceana																2
Planktonic indet.						1	3				10	1				1

Maszkowice Mb. Foraminiferal assemblage from the Koninki section consists of agglutinated and calcareous forms (s. 7/95 - Fig. 4; Tab. 1). Neither of taxa are numerous. Planktonic foraminifera though represented by single specimens are important for the age determination. According to the taxon ranges of the species identified as *Acarinina rotundimarginata* SUBBOTINA, *Turborotalia* cf. *cerroazulensis* (COLE), *Globigerina* cf. *corpulenta* Subbotina and *Globigerina eoceana* GUMBEL the age of this assemblage can be interpreted as not older than upper Middle Eocene and not younger than the lower Late Eocene (TOUMARKINE & LUTERBACHER, 1985; OLSZEWSKA et al., 1996).

Tab. 2. Distribution of the calcareous nannoplankton taxa in the selected samples.

	BELOVEZA FM.		BYSTRICA FM.			MASZKOWICE MB.		ZARZECZE FM. (TTT)									MASZKOWICE MB. (TTT)								
	63 98 N	9 98 N	64 98 N	66 98 N	52 98 N	3 99 N	4 99 N	60 97 N	7 99 N	8 99 N	11 99 N	12 99 N	13 99 N	1 98 N	2 98 N	8 98 N	75 98 N	76 98 N	77 98 N	6 95 N	109 98 N	110 98 N	70 97 N	6 98 N	7 98 N
Braarudosphaera bigelowii				X			X				X		X		X	X								X	
Chiasmolithus eograndis										X	X		X		X									X	
Chiasmolithus expansus													X												
Chiasmolithus gigas																			X		X			X	
Chiasmolithus grandis						X	X			X	X		X						X	X			X	X	
Chiasmolithus solitus											X		X												
Coccolithus pelagicus	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	
Cyclicargolithus floridanus	X		X	X	X	X	X												X		X	X	X	X	X
Dictyococcites bisectus	X				X														X	X					
Dictyococcites scripsae	X		X																	X	X				
Discoaster barbadiensis	X	X				X						X				X			X	X	X	X	X	X	
Discoaster bifax																				X			X	X	
Discoaster binodosus													X	X							X		X	X	
Discoaster deflandrei	X					X										X	X		X	X		X	X	X	
Discoaster delicatus											X														
Discoaster distinctus												X	X			X			X		X	X			
Discoaster kuepperi													X			X			X		X				
Discoaster lodoensis													X	X		X	X	X	X		X	X	X		
Discoaster multiradiatus											X			X	X				X					X	
Discoaster saipanensis														X	X				X	X					
Discoaster strictus													X						X		X		X		
Discoaster tani																	X	X	X	X	X	X	X	X	X
Discoaster tani nodifer																			X	X	X		X	X	
Ericsonia formosa	X			X		X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Ericsonia subdisticha																			X						
Fasciculithus sp											X														
Helicosphaera bramlettei													X						X		X			X	
Helicosphaera compacta							X						X	X		X								X	
Helicosphaera dineseni													X												
Helicosphaera euphratis																			X						
Helicosphaera heezenii													X												
Helicosphaera lophota				X		X															X			X	
Helicosphaera cf. reticulata																			X					X	
Helicosphaera seminullum																								X	
Lophodolithus nascens											X														
Neococcolithes dubius	X						X						X				X		X			X	X	X	
Pemma sp.								X																X	
Pontosphaera multipora							X				X													X	
Reticulofenestra dictyoda			X		X	X												X					X		
Reticulofenestra hillae				X																					
Reticulofenestra umbilica						X																			
Sphenolithus editus								X	X				X											X	X
Sphenolithus moriformis	X			X			X	X	X	X	X	X			X	X	X	X	X	X		X		X	X
Sphenolithus pseudradians													X	X				X			X				
Sphenolithus radians				X		X		X	X	X			X		X	X	X	X	X	X			X	X	X
Toweius crassus									X	X	X	X													
Toweius gammation			X			X	X								X			X	X	X	X			X	X
Toweius magnicrassus									X	X										X					
Toweius ocultatus											X														
Transversopontis pulcher							X																	X	
Transversopontis pulcheroides							X																	X	
Tribrachiatus orthostylus									X	X			X	X	X	X	X			X		X			X
Zygrhablithus bijugathus	X		X		X	X	X	X			X	X	X		X	X	X		X	X	X		X	X	X

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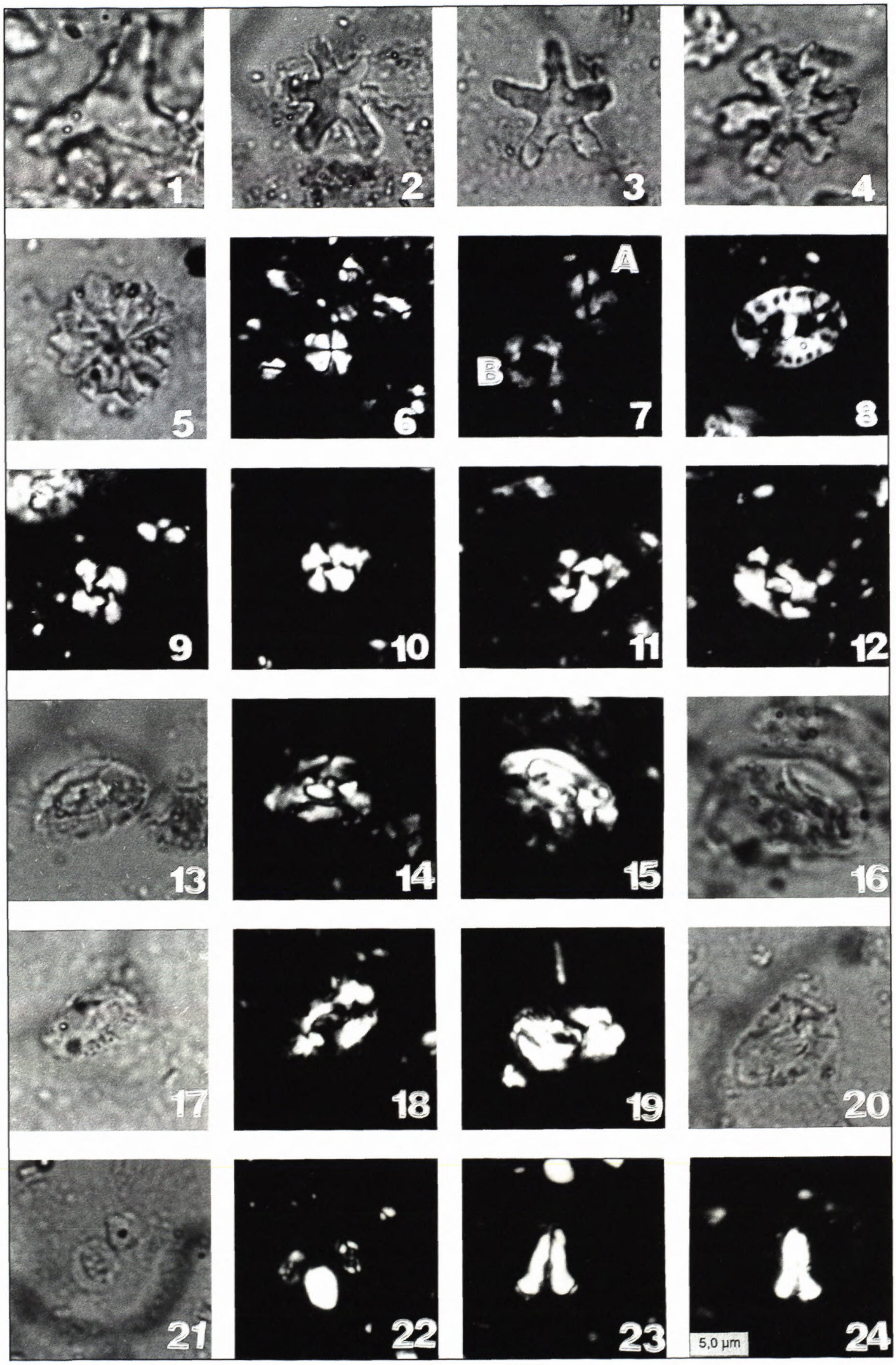

Fig. 8. LM microphotographs of the selected taxa of calcareous nannoplankton.

Calcareous nannoplankton

Konina–Lubomierz sequence

Beloveža Fm. (ss. 63/98/N, 9/98/N). The examined samples from this formation (Fig. 3, Tab. 2) contain fairly well preserved calcareous nannoplankton assemblages of low diversity. The autochthonous assemblage is dominated by *Cyclicargolithus floridanus* (ROTH & HAY) and *Coccolithus pelagicus* (WALLICH) whereas *Zygrhablithus bijugathus* (DEFLANDRE), *Reticulofenestra dictyoda* (DEFLANDRE & FERT) and *Sphenolithus radians* GRASSE are less common. Because of a lack of diversity the zone assignment was difficult to establish. The only species which indicates the age is *Cyclicargolithus floridanus* (ROTH & HAY). According to Aubry (1986) its first occurrence takes place in the upper part of NP 16 (Middle Eocene).

Bystrica Fm. (ss. 64/98/N, 66/98/N, 52/98/N, Fig. 3). The examined samples yielded the poorly preserved calcareous nannoplankton assemblage of very low diversity. The autochthonous assemblage is dominated by *Cyclicargolithus floridanus* (ROTH & HAY) and *Coccolithus pelagicus* (WALLICH) whereas *Zygrhablithus bijugathus* (DEFLANDRE), *Reticulofenestra dictyoda* (DEFLANDRE) and *Sphenolithus radians* GRASSE are less common. The only species which indicates the age, zone NP 16, is *Cyclicargolithus floridanus* (ROTH & HAY) (see Aubry, 1986).

Maszkowice Mb. (ss. 3/99/N, 4/99/N, Fig. 3, Tab. 2). The samples from this strata yielded fairly well preserved and moderately diverse calcareous nannoplankton assemblages, characterised by the occurrence of *Cyclicargolithus floridanus* (ROTH & HAY), *Ericsonia formosa* (KAMPTNER), *Zygrhablithus bijugathus* (Deflandre), *Neococcolithes dubius* (DEFLANDRE), *Chiasmolithus grandis* (BRAMLETTE & RIEDEL), *Coccolithus pelagicus* (WALLICH), *Sphenolithus radians* GRASSE, *Discoaster deflandreii* BRAMLETTE & RIEDEL, *Discoaster binodosus* Martini. Furthermore, the species *Helicosphaera compacta* BRAMLETTE & WILCOXON was identified in the sample 4/99/N, whose biostratigraphic range is problematic. This taxon was reported by Martini and Muller (1986), Perch-Nielsen (1985) from the upper part of NP 17, although, according to Aubry (1986), *Helicosphaera compacta* BRAMLETTE & WILCOXON ranges from as low as the upper part of NP 16 (see also THEODORIDIS, 1984). Therefore the zone assignment of the described formation should be based on the first occurrence of *Cyclicargolithus floridanus* (ROTH & HAY) and *Helicosphaera compacta* BRAMLETTE & WILCOXON. In conclusion, the calcareous nannoplankton from the Maszkowice Mb. belongs to zone NP 16 and it is not older than Late Middle Eocene.

Tobołów-Turbaczyk sequence

Zarzecze Fm. (ss. 60/97/N, 7/99/N, 8/99/N, 11/99/N, 12/99/N, 13/99/N, 1/98/N, 2/98/N, 8/98/N, Fig. 4, Tab. 2). The samples collected from the lower part of the formation (7/99/N, 8/99/N, 11/99/N, 12/99/N, 13/99/N) contain poorly to moderately well preserved calcareous nannoplankton assemblages of low diversity except for sample 13/99/N. The assemblages determined from samples 7/99/N, 8/99/N, 11/99/N, 12/99/N, do not contain any index species except for *Tribrachiathus orthostylus* SHAMARAI, whose first occurrence is within NP 10. At the same time the presence of *Sphenolithus moriformis* (BRONNIMANN & STRADNER) would indicate the age of the samples as being not older than NP 12. The lower boundary of NP 12 zone is usually marked by the FO of *Discoaster lodoensis* BRAMLETTE & RIEDEL, which was not found in the assemblages from the samples 7/99/N, 8/99/N, 11/99/N, 12/99/N. In the absence of *Discoaster lodoensis* BRAMLETTE & RIEDEL the first occurrence of *Toweius gammation* (BRAMLETTE & SULLIVAN) and *Discoaster kuepperi* STRADNER can be used to approximate the lower boundary of Zone NP 12 (see VAROL, 1989). However, the above mentioned species were not found either. It is also necessary to discuss the biostratigraphic range of *Toweius crassus* (BRAMLETTE & SULLIVAN). PERCH-NIELSEN (1985) following BUKRY (1973), suggested that the bottom of the Zone NP 13 can be approximated by the first occurrence of this species. However, on the Black Sea coast, north-east of Istanbul, *Toweius crassus* (BRAMLETTE & SULLIVAN) was found in NP 11 (Varol, 1989). Taking into account all above information the age of the samples 7/99/N, 8/99/N, 11/99/N, 12/99/N should be determined as not older than NP 12.

Younger assemblage was obtained from sample 13/99/N (Fig. 4). The assemblage is characterised by the occurrence of *Chiasmolithus eograndis* PERCH-NIELSEN,

1-Tribrachiatus orthostylus SHAMRAI (Konina 8/98N), 2- Discoaster tani BRAMLETTE & RIEDEL (Koninki 110/98N), 3- Discoaster tani BRAMLETTE & RIEDEL (Poręba 77/98N), 4 - Discoaster deflandrei BRAMLETTE & RIEDEL (Poręba 77/98N), 5 - Discoaster barbadiensis TAN (Poręba 77/98N), 6 - Sphenolithus moriformis (BRONNIMANN & STRADNER) (Konina 8/98N), 7a - Coccolithus pelagicus (WALLICH) (Lubomierz 6/98N), 7b - Reticulofenestra dictyoda (DEFLANDRE & FERT) (Lubomierz 6/98N), 8 - Transversopontis pulcher PERCH-NIELSEN (Lubomierz 6/98N), 9 - Cyclicargolithus floridanus (ROTH & HAY) (Koninki 52/97N), 10 - Cyclicargolithus floridanus (ROTH & HAY) (Poręba 63/98N), 11 - Cyclicargolithus floridanus (ROTH & HAY) (Koninki 109/98N), 12 - Helicosphaera lophota BRAMLETTE & SULLIVAN (Lubomierz 6/98N), 13 - Helicosphaera cf. dineseni PERCH-NIELSEN (Poręba 66/98N), 14 - Helicosphaera cf. dineseni PERCH-NIELSEN (Poręba 66/98N), 15 - Helicosphaera compacta BRAMLETTE & WILCOXON (Konina 13/99N), 16 - Helicosphaera compacta BRAMLETTE & WILCOXON (Konina 13/99N), 17 - Helicosphaera cf. reticulata BRAMLETTE & WILCOXON (Lubomierz 6/98 N), 18 - Helicosphaera cf. reticulata BRAMLETTE & WILCOXON (Lubomierz 6/98N), 19 - Helicosphaera cf. euphratis HAQ (Poręba 77/98N), 20 - Helicosphaera cf. euphratis HAQ (Poręba 77/98N), 21- Ericsonia subdisticha (ROTH & HAY) (Poręba 77/98N), 22 - Ericsonia subdisticha (ROTH & HAY) (Poręba 77/98N), 23 - Zygrhablithus bijugathus (DEFLANDRE) (Lubomierz 6/98N), 24 - Zygrhablithus bijugathus (DEFLANDRE) (Poręba 77/98N).

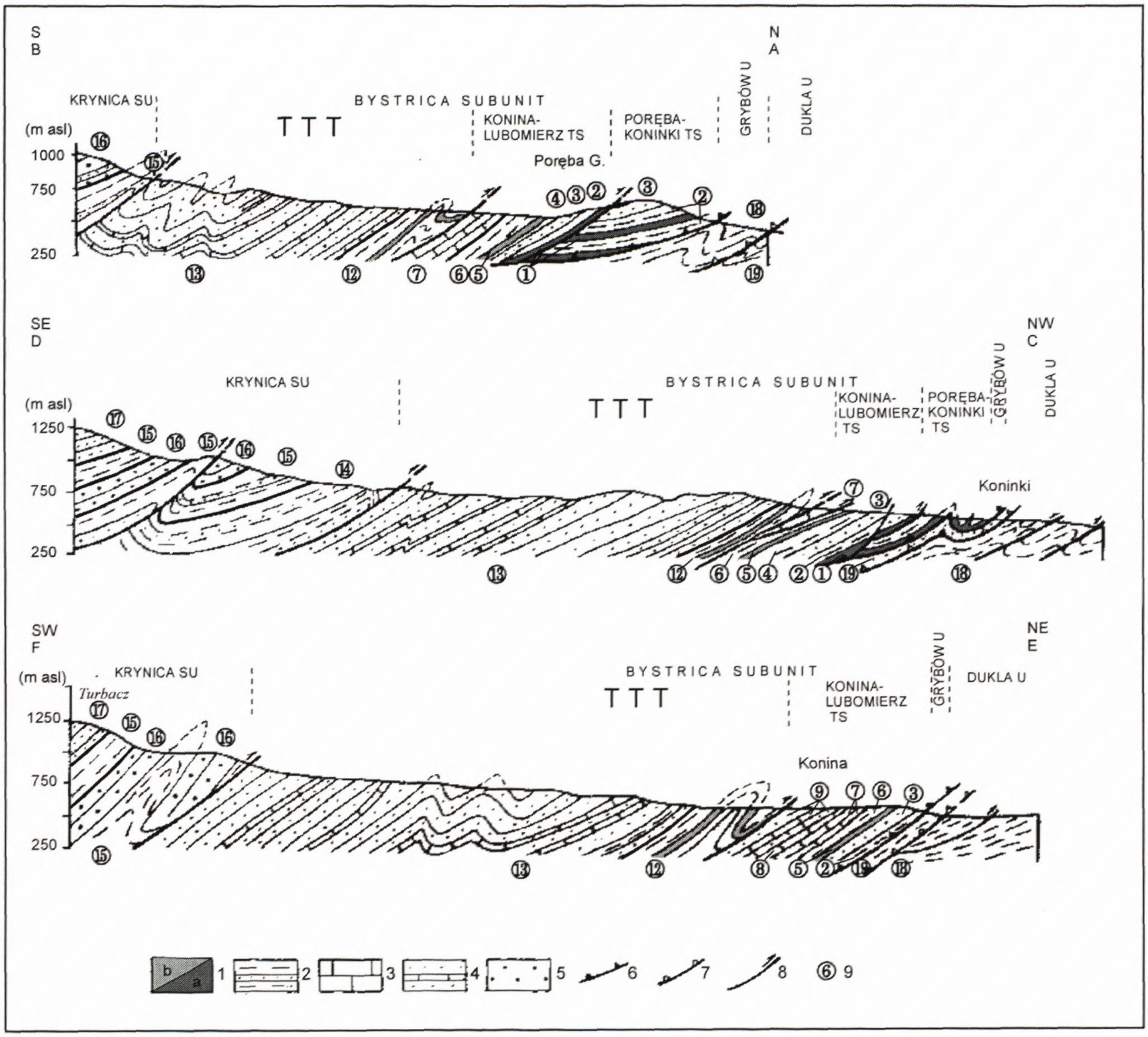

Fig. 9. Geological cross-sections. 1-variegated shales, a-Turonian-Senonian, b-Eocene, 2-thin-bedded turbidites, 3- marls, 4- thick-bedded sandstones and marls, 5-conglomerates and sandstones, 6-Grybów overthrust, 7-Magura overthrust, 8-other overthrusts, 9-lithostratigraphic units: 14- Szczawnica Fm., 15-Zarzecze Fm., 16-Krynica Mb. of the Zarzecze Fm., 17-Piwniczna Ss. Mb. of the Magura Fm. For other explanations see Fig. 3

Chiasmolithus expansus (BRAMLETTE & SULLIVAN), *Tribrachiatus orthostylus* SHAMARAI, *Discoaster binodosus* MARTINI, *Discoaster lodoensis* BRAMLETTE & RIEDEL, *Discoaster kuepperi* STRADNER, *Discoaster strictus* STRADNER, *Ericsonia formosa* (KAMPTNER), *Helicosphaera compacta* BRAMLETTE & WILCOXON, *Sphenolithus pseudoradians* BRAMLETTE & WILCOXON, *Sphenolithus radians* GRASSE, *Zygrhablithus bijugathus* (DEFLANDRE). The youngest taxon of this assemblage is *Helicosphaera compacta* BRAMLETTE & WILCOXON, having its first occurrence in NP 16 (see Aubry, 1986), whereas the occurrence of *Tribrachiatus orthostylus* SHAMARAI and *Discoaster lodoensis* BRAMLETTE & RIEDEL is believed to be the result of reworking.

In the Lubomierz section (Fig. 4) the youngest calcareous nannoplankton assemblages were obtained from samples 1/98/N, 2/98/N, 8/98/N (Fig. 4, Tab. 2). *Coccolithus pelagicus* (WALLICH), *Ericsonia formosa* (KAMPTNER) are the most commonly recorded species. The species which are also common, though to lesser extent are *Discoaster saipanensis* BRAMLETTE & RIEDEL, *Sphenolithus moriformis* (BRONNIMAN & STRADNER), *Sphenolithus radians* GRASSE , *Zygrhablithus bijugathus* (DEFLANDRE). The zone assignment is based on the first occurrence of *Helicosphaera compacta* BRAMLETTE & WILCOXON, as upper part of NP 16. In conclusion, the age of the Zarzecze Fm. could be established as the Early to Middle Eocene (NP 11-16)

Maszkowice Mb. (ss. 75/98/N, 76/98/N, 77/98/N, 6/95/N, 109/98/N, 110/98/N, 70/97/N, 6/98/N, 7/98/N, Fig. 4, Tab. 2). The examined samples yielded fairly well preserved and diverse calcareous nannoplankton assemblages, characterised by the occurrence of *Cyclicargolithus floridanus* (ROTH & HAY), *Coccolithus pelagicus* (WALLICH), *Chiasmolithus grandis* (BRAMLETTE & RIEDEL), *Dictyococcites bisectus* (HAY), *Discoaster strictus* STRADNER, *Discoaster tani* (BRAMLETTE & RIEDEL), *Discoaster tani nodifer* (BRAMLETTE & RIEDEL), *Discoaster saipanensis* BRAMLETTE & RIEDEL, *Ericsonia formosa* (KAMPTNER), *Helicosphaera compacta* BRAMLETTE & WILCOXON, *Sphenolithus pseudoradins* BRAMLETTE & WILCOXON. Such an association of calcareous nannoplankton is believed to be indicative of the upper part of NP 17 as the first occurrence of *Dis-*

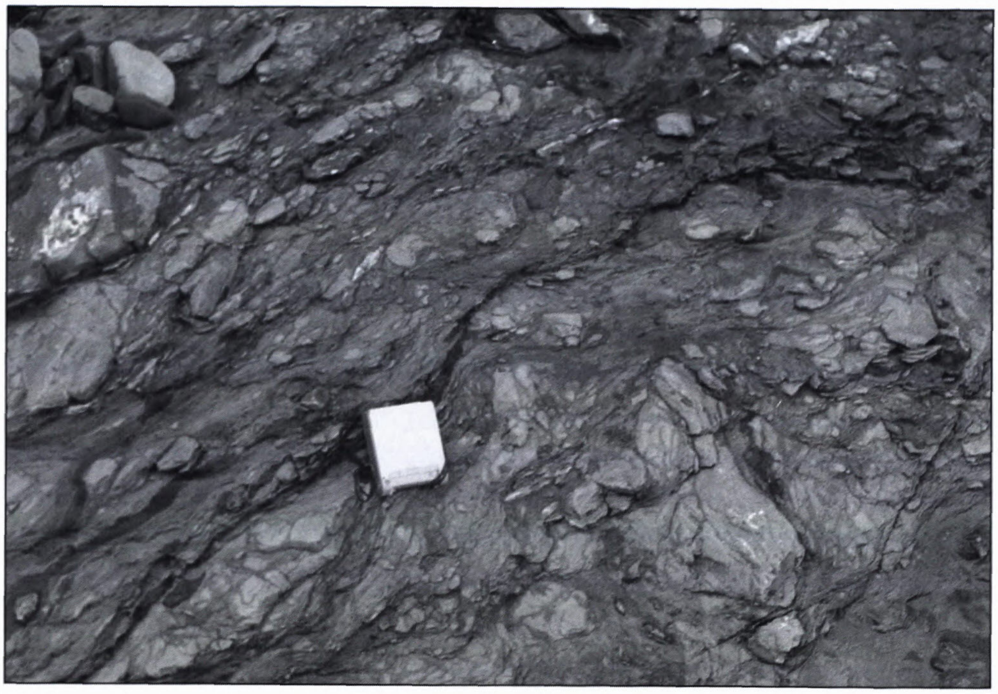

Fig. 10. Chaotic "melange" type deformation immediately above the Magura sole thrust (Lower Senonian deposits) in the Poręba Stream.

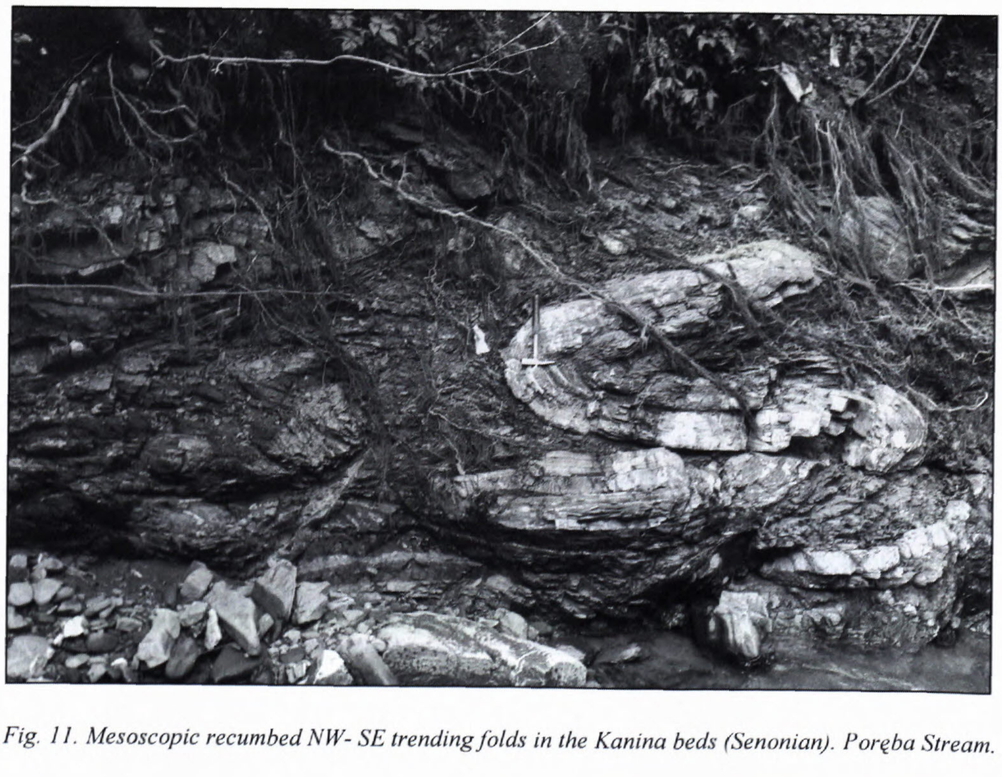

Fig. 11. Mesoscopic recumbed NW- SE trending folds in the Kanina beds (Senonian). Poręba Stream.

Fig. 12. Mesoscopic foult-thrust related fold in the Zarzecze Fm. of TTT. Poręba Stream.

coaster tani (BRAMLETTE & RIEDEL) is taking place in the middle part of NP 17 (see Bukry, 1973). The absence of *Chiasmolithus solitus* (BRAMLETTE & SULLIVAN) whose last occurrence marks the lower boundary of NP 17 is proof of such zone assignment. An exception is sample 77/98/N in which the species *Helicosphaera euphratis* HAQ was found. According to PERCH-NIELSEN (1985) this taxon appears for the first time in the middle part of NP 18 Zone. In conclusion, the lower part of Maszkowice Mb. of TTT should be assigned to zones NP 17 and NP 18 (Middle/ Late Eocene). However, the younger age of the upper part of the formation (NP. 19/20) cannot be excluded (see CABAJ, 1993) as only the samples from the lower part of this formation contained calcareous nannoplankton assemblages, which allowed age determination.

Structure

The area in question is located in the middle part of the Magura Nappe on the southern margin of the MDW and about 15 km southward from the front of the nappe (Fig. 1). The Magura Nappe is very flatly overthrust onto the Oligocene Krosno Fm. of the MDW (see Burtan et al., 1978 a; Mastella, 1988). The narrow and discontinuous Grybów Unit is wedged between the Dukla and Magura units. The Bystrica Subunit builds up the frontal thrust of the Magura Nappe between Olszówka and Lubomierz and consists of three thrust-sheets which contain characteristic sequences of deposits. From the north to the south there are: Poręba Wielka-Koninki (Albian-Paleocene), Konina-Lubomierz (Turonian-Middle Eocene) and Tobołów-Turbaczyk (Lower-Middle/ ?Upper Eocene) thrust-sheets (Figs. 2, 9). The lower, Poręba Wielka-Koninki thrust sheet reveals a decreasing degree of deformation from the 40-50 metre complex of chaotic "melange" type deformation (Fig. 10), described by Burtan et al. (1978 b) as "wildflysche" immediately above the Magura sole thrust, through the mesoscopic recumbed NW-SE trending folds (Fig. 11) to the NW-SE trending imbricated folds. The next thrust-sheet is 1,5-2 km wide (Figs. 2, 9) and forms a moderately south-dipping monocline. Along this thrust, numerous mesoscopic WNW-ESE and NW-SE trending folds have been observed. On the boundary between the complexes with different competence (eg. Łabowa/ Beloveža and Beloveža/Bystrica fms.) inverse faults, parallel to the frontal thrust have been documented. They caused a reduction of the thickness of the Łabowa and Beloveža fms. The TTT is characterized by strongly deformed Zarzecze Fm. and monoclinally, south-dipping Magura Fm. The lower part of the Zarzecze Fm. displays numerous mesoscopic thrust-fault propagating folds (NE-SW and NW-SE) (Fig. 12). In the Poręba Górna and Konina sections, the middle part of the formation reveals a segment of the south-dipping overturned strata, measuring 100 m in length. Distinguished in this paper, the Tobołów-Turbaczyk thrust sheet (TTT) has been documented along a 25 km long belt. This structure is cut from the west and east by the Rabka and Zbludza-Zalesie transversal, submeridian, normal faults respectively (Fig. 1). The Krynica and Bystrica (TTT) subunits are separated by W-E trending overthrust (Figs. 1, 2, 9). The Krynica subunit are thrust onto the youngest deposits (Middle/ ?Upper Eocene) of the Bystrica (TTT) subunit. The frontal part of the Krynica thrust is build up by a few imbricated folds composed of the Szczawnica and Zarzecze fms., followed by a syncline filled with the Piwniczna Mb. of the Magura Fm. The Magura Nappe on the southern margin of the MDW is disturbed by three

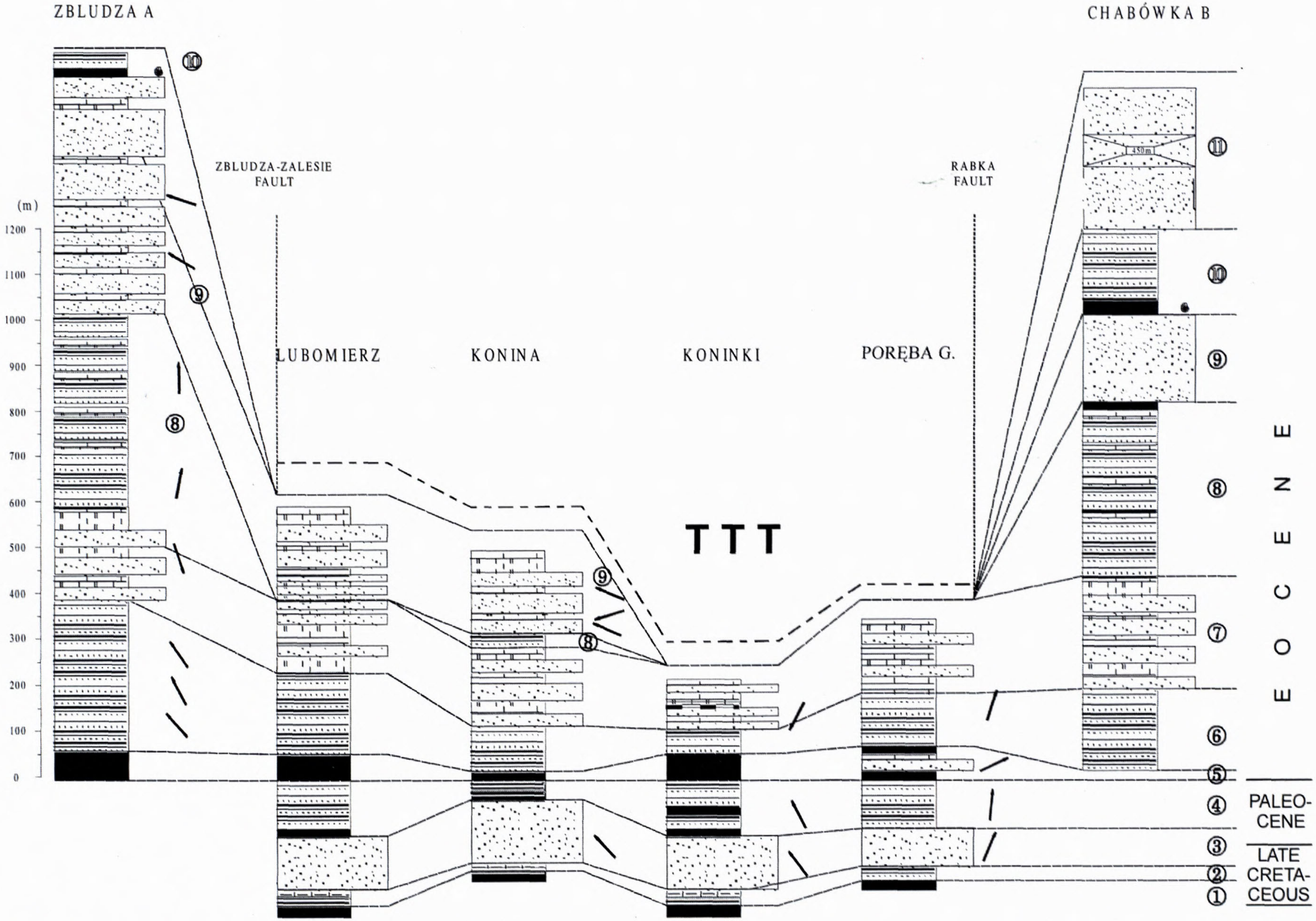

Fig. 13. Lithostratigraphic correlation of the Bystrica Subunit on the southern margin of MDW with Chabówka (B) and Zbludza (A) sections (after Oszczypko, 1991). For explanations see Fig. 3.

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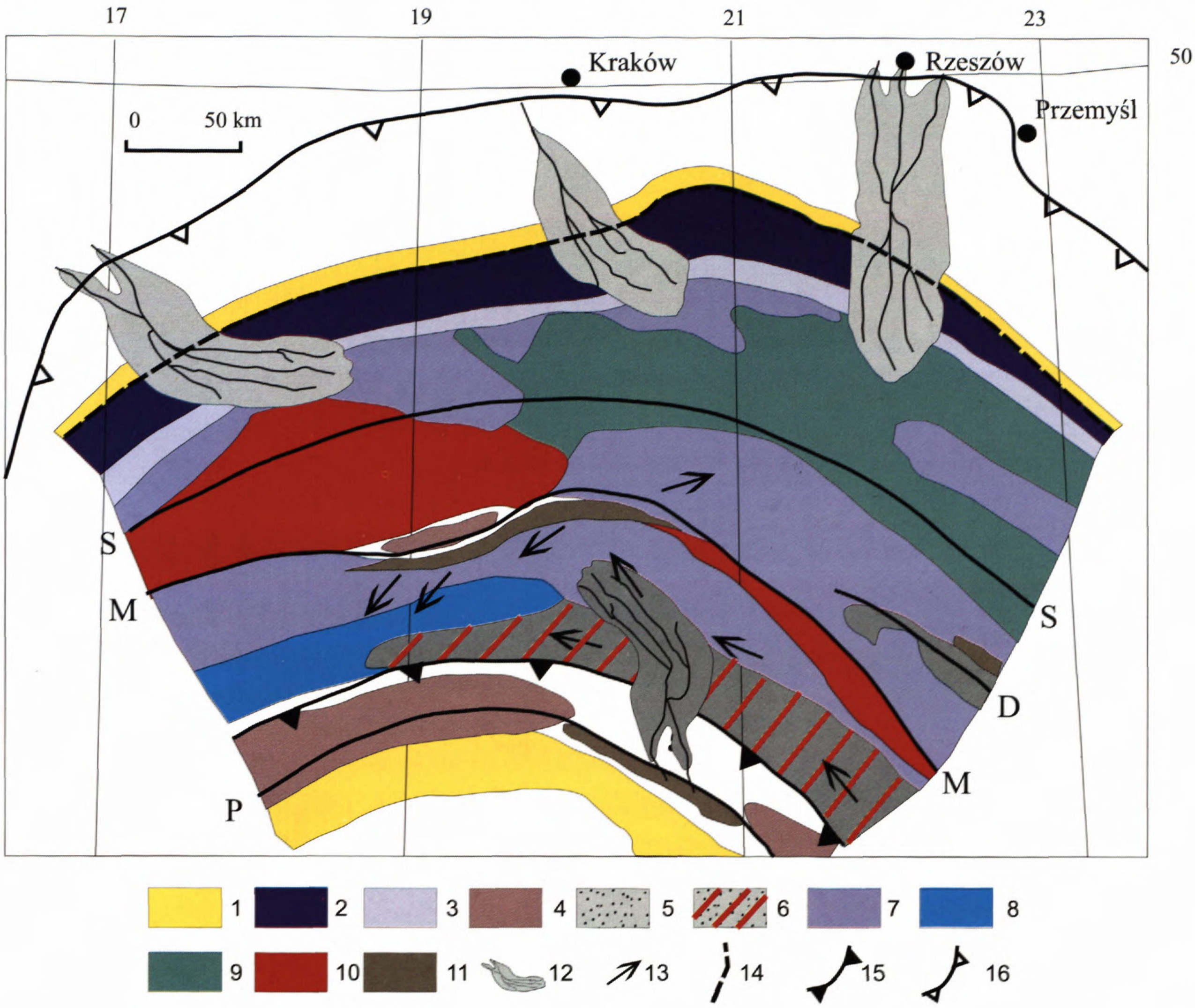

Fig. 14. Middle/ Late Eocene paleogeography of the Polish sector of the Outer Carpathian basin (after Książkiewicz, 1962; Oszczypko, 1998, suplemented). 1-littoral facies, 2-shelf facies, 3-slope facies, 4-pelagic slope marls, 5-chanel-fan deposits, 6-variegated shales of the Mniszek Mb.,7-distal turbidites, 8-silico-carbonate turbidites, 9-hemipelegic green shales, 10-hemipelagic variegates shales, 11- intrabasinal source area, 12-delta, 13-paleotransport, 14- zero line of Wiese vector, 15-active margin of accretionary wedge, 16-present-day front of the Carpathians.

submeridional faults located at the western (Olszówka) and eastern margins of the window.

Lithostratigraphic correlation and paleogeographical implications

The Eocene deposits of the Konina-Lubomierz and Tobołów-Turbaczyk sequences have themselves been compared as well as, with the Zbludza and Rabka sections (Figs. 1, 13). Generally, there is good lithostratigraphic correlation between Konina-Lubomierz trust sheet sections and Zbludza and Rabka sections, though some differences can be observed. In the comparison with complete Zbludza and Rabka sections the Poręba Górna, Koninki, Konina and Lubomierz sections display a reduction in thickness of the Beloveža and Żeleźnikowa fms. and the Maszkowice Mb. of the Magura Fm. For example, the thickness of the Eocene strata in the Poręba Górna is about 200 m., up to 250 m in Koninki and about 500 m. in Konina sections, whereas in the Zbludza and Rabka sections it reaches more than 1500 m. The lack of the Mniszek and Poprad members of the Magura Fm. is also very significant. The reduction in thickness of the Beloveža Fm. is probably of sedimentary and partly tectonic nature, whereas reduction in thickness and disappearing of the youngest lithostratigraphic units are tectonic in origin. It could be connected with formation of the Tobołów-Turbaczyk trust-sheet and extentional motions during the Middle Miocene uplifting of the Mszana Dolna tectonic window. The sections of the Konina-Lubomierz and Tobołów-Turbaczyk thrust sheets indicate the significant facies differences, particularly below the base of the Magura Fm. In the TTT, the Zarzecze Fm. (Lower-Middle Eocene) replaces the following litostratigraphic units typical of the Bystrica facies zone: the variegated shales of the Łabowa Fm. (Lower Eocene), Beloveža Fm. (Lower/Middle Eocene) and Bytrica and Żeleźnikowa fms. (Middle Eocene, see also Oszczypko, 1991). These facies differences could have been caused by the more southern positioning of the TTT sedimentary area in the Magura basin, with respect to the Bystrica facies zone. Thus, the Zarzecze Fm. of TTT was deposited in the northern, deeper and nonchanelized part of the Krynica facies zone, whereas all the other formations were deposited in the Bystrica facies zone. This is shown by the occurrence of the variegated shales, calcareous-free character of the majority of shales and lack of the Krynica Cgl. Mb. During the late Middle Eocene (NP 17 Zone) the Magura Sandstone fan first reached the TTT sedimentary area and then expanded into the Bystrica facies zone. (Fig. 14). Towards the axes of the basin the sandstones of the Maszkowice Mb. were replaced by the sandstones and marls (Bystrica Fm) and basinal turbidites (Beloveza Fm), whereas the abyssal plain was occupied by the Middle Eocene red shales (Łabowa Fm.) of the Rača facies zone (Oszczypko, 1992). From the comparison of the thickness of the Maszkowice Mb. in different parts of the Bystrica Subunit and TTT (see Oszczypko, 1991) it can be concluded that TTT represents the SE-NW (150-160ş) trending axial zone of the Middle Eocene Magura sandstone fan. At the beginning of Late Eocene (NP 18) during the HLS (Haq et al., 1987) the peripheral part of the Magura sandstone fan probably reached CCD. This resulted in the deposition of variegated shales of the Mniszek Sh. Mb. of the Magura Fm. In the TTT area the Mniszek Mb. was probably not deposited. Its equivalent could be represented by thin-bedded turbidites in the Poręba Górna and Lubomierz sections. These deposits occur about 700 m. above the base of the Magura Fm (Fig. 4). The strongly tectonized Zarzecze Fm. could represent a suture zone of the early Middle Eocene accretionary wedge, overlapped by the Magura sandstone fan. During the Lutetian/Bartonian time, this suture zone was probably dormant and then (Priabonian) reactivated before the deposition of the Malcov Fm. (see Oszczypko, 1998). The Middle/Late Eocene paleogeographic situation of the Magura basin as a part of the Northern Tethys is shown in figure 14. Present-day fault boundaries of TTT located in Rabka and Zbludza probably developed along the former margin of the fan. According to Malata et al. (1996) the Zbludza-Zalesie normal fault, which bounded TTT from the east, was formed after the Middle Badenian and prior to Late Badenian-Sarmatian deposition in the Nowy Sącz Basin.

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New mineralogical and paragenetic knowledge about siderite veins in the vicinity of Vyšná Boca, Nízke Tatry Mts.

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Abstract. Siderite vein mineralization occurs near tectonic contact of the Tatricum and Veporicum in eastern part of the Ďumbier Nízke Tatry Mts. The most intensive exposure of the mineralization is in Tatricum tectonic unit in the Vyšná Boca area. The area is composed of regionally metamorphosed rocks of the Mesozoic envelope. We have studied two vein systems: southern (Paurovská, Kliesňová, Helena, Rovienky) and northern (Pod Štefanom, Kumštová, Králička) and several independent occurrences. Veins occur in mylonite zones and have WSW - ENE strike (250°), about 75° southward dip, and their average thickness is 0.5 m. Silification, presence of pyrite and arsenopyrite is characteristic for hydrothermal changes of surrounding rocks. The main vein minerals are siderite, barite and quartz. Pyrite, tetrahedrite and chalcopyrite are dominant sulphide minerals. Sphalerite, arsenopyrite and hematite from oxide minerals are rear. Occurrences of Ni-Co-bearing minerals and sulphosalts of aikinite isotype series are characteristic. Presence of Ag-Bi-bearing sulphosalts and carrollite are exceptional. Ankerite, galenite and tennantite are abundant in some veins only. Oxidized zone is developed mainly in northern vein systems where Fe-hydroxides and Ca-carbonates are the most abundant minerals. Siderite, quartz and sulphide form several generations. After carbonate stage, there was quartz-sulphide stage and then sulphosalt mineralization stage at the locality Paurovská. The latest generation of siderite and hematite veins penetrates into rocks of Mesozoic envelope.

Key words: Mineralogy, siderite veins, carbonates, Cu-Pb-Bi sulphosalts, Western Carpathians.

Introduction

An old mining village Vyšná Boca is located at the end of Bocianska dolina valley, between Ďumbier and Kráľová hoľa parts of Nízke Tatry Mts., 2.5 km NNE from the Čertovica saddle. Numerous tailing piles, feighs, discovery claim and mine galleries, some of them still accessible, are witnesses of the mining activities around the dwelling. According to Bergfest (1952), gold, silver, copper, antimony and later also iron were mined in this area in the past. The oldest records of mining activities near Boca (there is no distinction between Nižná and Vyšná Boca in older literature) are from 1271, when the King Štefan V. confirmed privileges for mining in Boca again (Bergfest, 1952). In 13-th century, gold was cradled in Boca stream, later it was also mined from ore veins. After 1955 (Bergfest, 1952), when the gold mining was on the top, the gold mining started to decline because of discord of mine owners and mine superintendents, low productivity and flooding of some mines. The last reports about gold mining are from the second half of 19-th century, when the mining was definitely over. Maderspach (1880) reports mining of gold, copper and silver and later also limonite and Fe-bearing carbonates in a mine Pod Štefanom. Papp (1919) evaluated this area as perspective for Fe-ore mining because only top horizons of the veins had been mined, and thus there was a significant amount of high quality ore in deeper parts. During the World War II., Kuthan (1941) again confirmed occurrences of gold, antimony, galenite and gold-bearing pyrite in the area SW from Vyšná Boca. During 50s a prospecting for iron ores took place, the emphasise was put on Fe-ore reserves (Zoubek, 1951; Zoubek and Rus, 1951; Čillík, 1955). The results from two galleries at the deposit Paurovská and Kliesňová dolina valley were encouraging, however, the mining was terminated earlier than the ore vein was reached. The mineralogy of the ore deposits Kliesňová and Pod Štefanom was described by Juriga (1958). Zoned arsenopyrite from the Vyšná Boca area was described by Stankovič and Siman (1992). Beside mentioned works, the complete mineralogy of the Vyšná Boca area was described by Koděra et al. (1990, 1990a), Slavkay et al. (1988), Slavkay and Chovan (1990) and Chovan et al. (1996). In mineralogical exposition of Natürhistorische Museum in Vienna, there are two several centimetres large strontianite minerals with radiated structure from the locality "Bocza, Ungarn". It is no doubt, that these samples were found in Austrian – Hungarian Monarchy (the name Bocza was used for today villages Vyšná and Nižná Boca).

Geological characteristics of the area.

Carbonate-quartz-sulphide ore mineralization occurs in the vicinity of Vyšná Boca, dominantly in rocks of crystalline complexes of Tatricum, northward of the Čertovica tectonic lineament. Biotite to two-mica paragneisses with banded structure are the most common metamorphic rocks of crystalline complexes. Garnet-biotite and other types of paragneisses and metaquartzite are less common. Westward of Vyšná Boca Maheľ (1986) describes also light-grey orthogneisses with quartz and microcline porphyroblast. In addition to acidic metamorphic rocks, there are also thin layers of amphiboles. Two types of granitoid rocks represent the rocks of the studied area: Ďumbier and Králička type. Ďumbier type, represented by biotite tonalite to granodiorite, is the most common granitoid rock in the eastern part of the Ďumbier crystalline complex (Biely et al., 1992). Petrík et al. (1993) classified this type of metaaluminous granitoid rocks to I-type granitoid. Cambel et al. (1990) concluded that the temperature of crystallisation was 670 - 700 °C and the age was 368±22 Ma (Rb/Sr method). Králička granite is less abundant (Biely et al., 1992). Peraluminous biotite to two-mica granite to granodiorite (Králička type) (Dupej and Siegl, 1984) forming 9.5 km long and max. 800 width strip from Veľký Gápeľ to Vyšná Boca was classified by Petrík et al. (1993) to S-type granitoid. Cambel et al. (1990) concluded that the temperature of crystallisation was 670-690 °C and the age of the granite was 365±17 Ma (Rb/Sr method). Granitoid and also metamorphic rocks are sometimes transected by up to several tens centimetres thick pegmatite and apatite veins. The Mesozoic envelope rocks composed mainly of low Triassic quartz of Lúžňan formation, sandstone and greywackes are rare, they occur mainly in eastern part of the studied area (at the end of the Kumštová and Starobocianska dolina valley). Rauwackes (at the end of the Starobocianska dolina valley under the Bocianske sedlo pass) and mottled shales and sandstones of Verfen formation are rare.

Mineral deposit characteristics of the area

There are two main types of ore mineralization in the studied area: siderite and gold. Siderite mineralization occurs mainly in mylonite zones within metamorphic rocks WSW to SWS-ward of Vyšná Boca. Gold mineralization is represented by quartz veins with sulphides and gold, which occurs in granitoid rocks westward and north-westward of Vyšná Boca. More detail division is the object of the ongoing research.

The two main vein bodies south-westward and westward of the village Vyšná Boca (Fig. 1) were subjected to the field, economic geological and mineralogical research:

1. The southern vein system is represented by mineral deposit Paurovská - Kliesňová - Helena and occurrence Rovienky. Old mining works are located along mylonite zone that is developed in high-rank metamorphic rocks of crystalline complex (mainly gneisses) in that beds of medium-rank metamorphic amphibolite and pegmatite veins occur. The mining strike is 250°. Individual deposits are separated from each other with tectonic failures (Zoubek, 1951, Čillík, 1955, and others). Originally uniform vein is gradually branched from ENE to WSW. The vein branching has always direction toward SW. The vein is formed by numerous small veins at its SW end in Rovienky. The general vein strike in Kliesňová is from 245° to 270°, most often 250°. The vein dip is very variable and steep. The dip range is from 45° to 80° toward S to SE or SW (for example, the gallery Kliesňová kutacia; Juriga, 1958), the most dominant dip is 75° toward S (Čillík, 1955), the dip in the gallery Helena is 75° - 80°. The thickness of the vein Kliesňová is in a range from several ten centimetres to two meters (exceptionally up to 3 m). It is wavy vein with frequent broadening and tailing off. The depth reach of the Kliesňová vein is 150 m at least (Čillík, 1955). Cocarde, brecciated and combed structures are characteristic for this southern vein system.

The oxidised zone is almost not developed on this vein system. Small occurrences of iron hydroxides and goethite are in tailing pile of the Vyšná Helena gallery, Fe-baring arsenic minerals (pharmacosiderite, ferisymplesite) occur near the Čertovica pass on the mountain ridge Rovienka.

Significant galleries of the Paurovská area are Kutacia Paurovská, Stará Paurovská and Vyšná Paurovská; in the Kliesňová area there are galleries Vyšná and Nižná Prozretelnosť Božia, Kliesňová kutacia and Leopold; and in the Helena dolina valley there are galleries Nižná Helena, Vyšná Helena and Helena. These galleries are also centres of mining areas with the same names. In southern part of the mining area Helena there is also buried mine Zubau with Ni-Co mineralization.

2. The Northern vein system includes mineral deposits Pod Štefanom - Kumštová dolina valley (the mining area Eduard) - Králička. The veins have the same trend and position as veins from the southern vein system. For example, the length of the vein Pod Štefanom (Pod István) is 1.4 km, Fe-ore mining was in western part, Cu mineralization dominated in eastern part (Zoubek, 1951). There are dominantly siderite and barite, less dominantly quartz in the vein rock. Sulphide and hematite are disseminated in the vein rock. Pyrite and arsenopyrite are abundant in altered silicified zones. Oxidized zone is more developed than in the southern vein system, and Cu-bearing (malachite, azurite) and Fe-bearing (goethite, hematite) secondary minerals are abundant in this zone.

The locality **Bruchatý Grúnik** is located on southern slope of the Rovná hoľa Mts. in altitude 1435 m. above see level about 1.5 km north-westward of mineral deposit Pod Štefanom and about 3.5 km WNW from Vyšná Boca. According to Zoubek and Rus (1951) and also according to map by Biely et al. (1992), the vein is located in granodiorite to tonalite of the Ďumbier type, however, it is not excluded that it is located at the contact of gneisses with granodiorite rocks. The vein has brecciated structure and it is characteristic by presence of abundant medium-grained ankerite and sulphides (galenite and tetrahedrite). Ni-Co mineralization is also abundant.

On the southern slopes of the **Chopec Mt.** there is large amount of mining-works with Sb-Au mineralization that is not subjected to our ongoing research. About 1200 m westward of Vyšná Boca in the Králička type granites, there are tailing pile and old collapsed gallery. Its vein

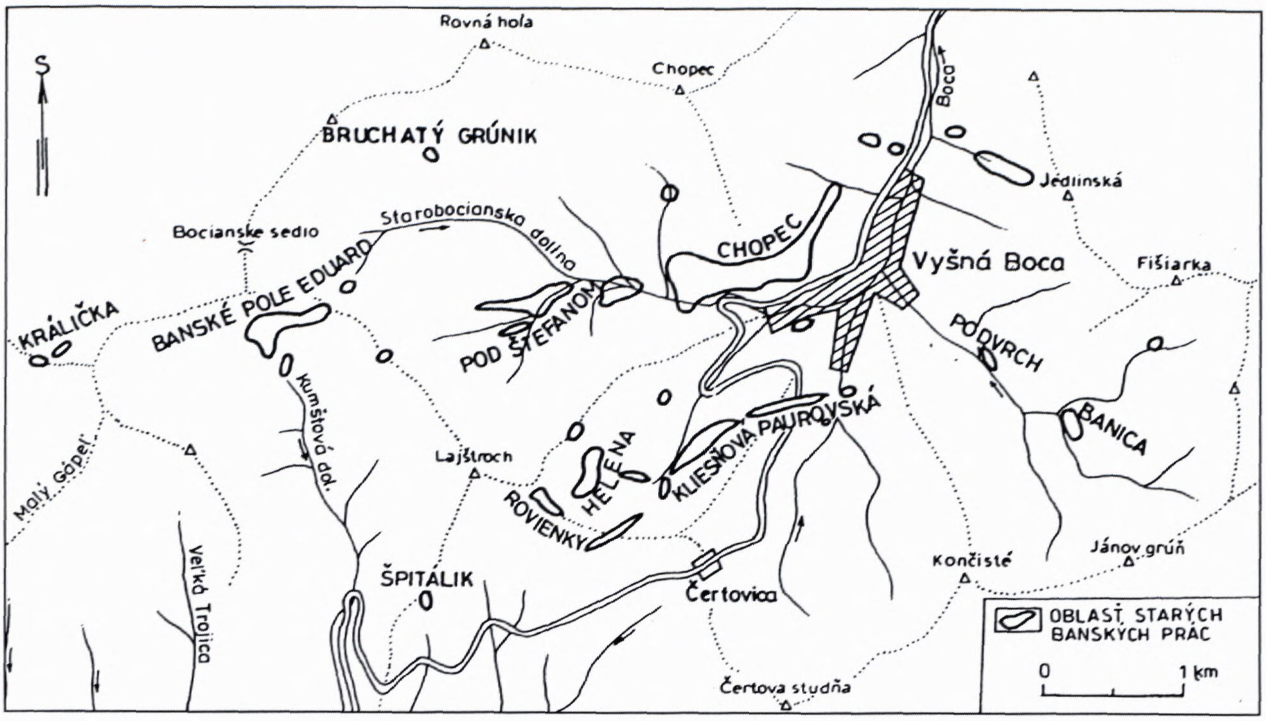


Fig. 1. Map of old mining activities in the vicinity of Vyšná Boca

rock contains large amount of sulphides (pyrite, galenite and tennantite). Its most abundant carbonate mineral is ankerite, however, siderite is also very common. Surrounding granitoid rocks are extensively altered, silicated and have extensive impregnation of pyrite and arsenopyrite. With respect to mineral parageneses and quantitative abundance of main minerals, we have classified the ankerite veins among carbonate mineralization.

All minor occurrences (**Banica, Fišiarka, Podvrch, Končistá**) mentioned in older references (Papp, 1919) are and were south-eastward to north-eastward of Vyšná Boca. Small carbonate lenses are in granodiorite to tonalite of the Ďumbier type or in gneisses of the Nízke Tatry crystalline complex. They are composed dominantly of weathered siderite, quartz and micas. Sulphides are represented by mostly strongly weathered pyrite. Most of the small mining activities (mainly feigh with little tailing piles) has already vanished.

Methodology of the research works

Majority of tested samples was picked up from tailing piles. 123 polished-sections and micro-sections had been made from the samples after their visual inspection and inspection under UV radiation (UVSL-58 lamp with wavelength of UV radiation, 254 - 366 nm). Microscopes Jenapol and Amplival made by Zeiss were used for microscopic studies. Immersion method of measurement of refractive index was used for initial identification of carbonates and barite. Reflectance of selected ore minerals was measured in Department of mineralogy ELTE in Budapest (microscope Leitz, standard: basal cat SiC, step 10 nm, wavelength 400-700 nm). Identification and initial analyses of chemical composition of carbonates was made by manometric and differential thermal analysis (DTA) (derivatograph MOM, type OD-102; conditions: charge 525 mg, TG 200 mg, DTA 0.5 V, DTG 2.5 V, temperature 1000 °C, rate of heat increase 10 °C/min.). RTG diffraction analyses of aragonite was made by Geologic Institute of Faculty of Natural Sciences of Comenius University with device DRON-3 under the following conditions: Cu/Ni, 20 kV, 40 mA, speed of arm advance 1°/min. Primary minerals were analysed by wave-dispersion (WDS) and energy-dispersion electron microprobe in GS SR Bratislava, device Jeol Superprobe 733 was used under conditions: 20 kV, 15-20 nA, beam diameter 3-5 μm, standards - arsenopyrite, pyrite, galenite, cinnabarite, Cu, Bi, Fe, Zn, Sb, Ag, Au, Co, Ni. The photographic pictures of compositions were taken with Jeol JSM-840 with 20-25 kV in GS SR Bratislava. All other analyses not mentioned in these papers are in papers by Ozdín (1996) or are in archives of both authors.

The results of the mineralogical research

The minerals are ordered according to mineralogical system (Strunz, 1982), except minerals of tetrahedrite group that are classified among sulphosalts (Makovický and Karup Möller, 1994). All sulphosalts are classified according the classification by Moëlo ed. (1994).

Primary minerals

Sphalerite, ZnS occurs only auxiliary in form of tiny, mostly microscopic allotriomorphic grains in association with tetrahedrite, chalcopyrite, pyrite, galenite, arsenopyrite and hematite within milky-white quartz (Fig. 2) in siderite veins in the vicinity of Vyšná Boca. Sphalerite is more abundant in centre part of tailing pile at Kliesňová and mainly at Bruchatý Grúnik where sphalerite forms up to 5 mm large clusters within carbonate-sulphide vein rock. Larger grains of allotriomorphic sphalerite sometimes contain higher amounts of inclusions of chalcopyrite. Sphalerite was identified with reflected light and preliminary by EDS analysis.

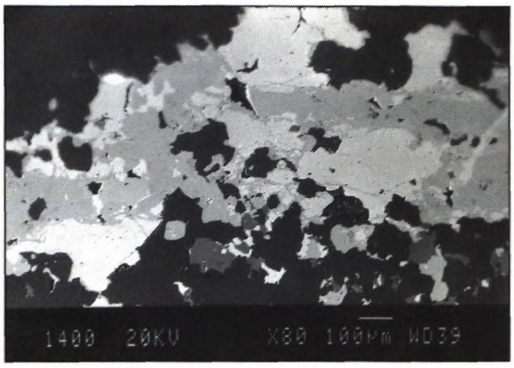


Fig. 2. Sphalerite (black-grey; in lower part) with tetrahedrite (light-grey) and chalcopyrite veins (dark grey) within quartz (black) from the mineral deposit Kliesňová.

Chalcopyrite $CuFeS_2$ belongs among main sulphide minerals in majority of siderite deposits, however, its quantity is variable from locality to locality. It is in association with tetrahedrite, pyrite, galenite, arsenopyrite, sulphosalts of bismuthite series and sphalerite, less with Ni-bearing diarsenides and Ni-Co-bearing sulphoarsenides within carbonate-quartz-sulphide veins where it forms small veins in hydrothermal milky-white quartz (for example Kliesňová, Helena etc.), less in siderite (Bruchatý Grúnik), or it is disseminated mainly in barite (Pod Štefanom). Small chalcopyrite veins (sometimes with pyrite) intersecting tetrahedrite can be often observed with help of reflected light. Sometimes it forms inclusions within tetrahedrite or skirts its allotriomorphic grains. Chalcopyrite itself contains inclusions of tetrahedrite, galenite, pyrite, sulphosalts of bismuthite-aikinite series and pavonite group. In samples from Kumštová dolina valley chalcopyrite forms filling of enclaves in metacrysts of pyrite. Chalcopyrite has sometimes optic zoning. It is locally intensively replaced with Fe-bearing hydroxides. It was preliminary identified by EDAX.

Cubanite (?), $CuFe_2S_3$ was sporadically found at the deposit Kliesňová, where it forms up to 2 mm long lamellas within chalcopyrite in association with tetrahedrite, sphalerite, and pyrite in quartz. In comparison to chalcopyrite, cubanite is more anisotropic and intensively laminated in reflected light. It was identified optically with reflected light.

Galena PbS usually occurs as inclusions in tetrahedrite and chalcopyrite, however, its occurrence with chalcopyrite, tetrahedrite, sphalerite and pyrite in siderite veins are rare. Sometimes it is more abundant in veins with barite (for example locality Pod Štefanom).

Samples of vein rock with abundant presence of galenite, tetrahedrite and another sulphides occur at locality Bruchatý Grúnik. They form several millimetres thick veins, nests with area up to several square centimetres and clusters within carbonate-quartz vein rock with brecciated structure. Mostly fine-grained idiomorphic galenite (grain size up to 1 mm) occurs in association with tetrahedrite, chalcopyrite, sphalerite, pyrite, arsenopyrite, tennantite, cobaltine and Ag-Pb-Bi- bearing sulphosalts. According to spectral analysis, the sample with high concentration of galenite from the locality Bruchatý Grúnik contains 89.2 ppm Ag and 0.06 ppm Au.

Galenite, together with tennantite and pyrite (Fig. 10), occur also on southern and eastern slopes of Chopok Mt. in rocs from tailing piles as noddles in quartz-ankerite vein rocks or as individual veins in granite. It occurs in association with quart-gold mineralization. Galenite was identified with reflected light and its chemical composition was studied by EMPA. The galenite from the locality Bruchatý Grúnik contains these accessory minerals: Bi 0 - 0.23, Ag 0 - 0.66, Sb 0 - 1.21, Cu 0.17 - 0.79, Fe 0 - 0.54 wt.%.

Carrollite $Cu(CoNi)_2S_4$ occurs only exclusively in the mining area Helena, where it is in association with cobaltine, gersdorffite, galenite, pyrite and minerals of tetrahedrite-tennantite series in arsenopyrite veins. It was preliminary identified by EDS analyses (Cu 13.82, Co 42.68, Ni 6.94, Fe 1.09, S 35.47, 100.00 wt.%).

Bismuthinite Bi_2S_3 occurs in siderite veins only rarely, but regularly in form of individual grains intergrowing with chalcopyrite (Fig. 3) and exceptionally also with tetrahedrite, or in form of allotriomorphic or hypidiomorphic grains freely occurring in quartz and exclusively also in siderite. It forms tiny needles and short-columnar crystals. At the locality Paurovská it occurs together with Ag-Bi-bearing sulphosalts (pavonite homoseries) and Cu-Pb-Bi- bearing sulphosalts (pecoite) into which it is gradually converted. Exceptionally it also contains inclusions of tetrahedrite. It is often chemically inhomogeneous. It was identified optically with reflected light and by WDS analysis (Fig. 7).

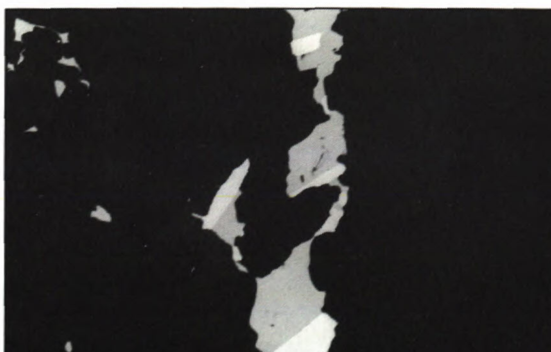


Fig. 3. Bismuthinite (white) on chalcopyrite vein (grey) in quartz (black) from the locality Paurovská.

Pyrite FeS_2 (cubic) is very abundant in silicified hydrothermal alteration zones in rock surrounding ore veins, where it occurs in two formations: 1. in intensively silicified zones in close proximity of ore vein, where more or less crushed and cataclastic pyrite rarely occurs in arsenopyrite veins. 2. in greater distances from ore veins, where alteration of rocks surrounding ore veins is weak. Pyrite is there abundantly disseminated and arsenopyrite does not occur there. Freely disseminated fine-grained pyrite is the main sulphide mineral disseminated in older fine-grained siderite in siderite veins. It often occurs together with chalcopyrite, sphalerite, galenite, arsenopyrite, and with another sulphides and Cu-Pb-Bi-bearing sulphosalts in siderite or ankerite in quartz veins.

At the deposit Pod Štefanom, pyrite, together with chalcopyrite and tetrahedrite, occurs in form of idiomorphic crystals or very tiny allotriomorphic crystals in pyrite-chalcopyrite veins transecting tetrahedrite. Pyrite also is abundant in thin, up to 3 mm thick arsenopyrite veins with Ni-Co mineralization at the locality Helena. Up to 2.5 mm large pyrite metacrystals with abundant inclusions of chalcopyrite, tetrahedrite, and galenite often occur at the Kumštová dolina valley and at the deposit Pod Štefanom. Pyrite itself forms inclusions within chalcopyrite and tetrahedrite. Sometimes it is recrystallised and replaced with marcasite. Freely disseminated fine-grained pyrite is the main ore mineral in one type of grey-white quartz at the locality Bruchatý Grúnik. It occurs here in association with galenite that often growth over the pyrite, forms network of veins within it, penetrates along fractures, fills open fractures and voids or it grow around individual pyrite grains. In zones rich in microlaminated hematite, the pyrite forms max. 2 mm large idiomorphic crystals with prevailing pentagonal dodecahedron shape. It is often chemically zoned. It posses sector (Chopec), concentric (Helena, Bruchatý Grúnik, Paurovská) or irregular (Chopec, Helena) zoning. It was identified optically with reflected light, with help of reflection curves, and by EMPA (Tab. 1). Gold bearing pyrite occurs in several quartz-sulphide veins. In some types of pyrite, it is the crystal cores that are enriched with the gold. (Tab. 1, Analyses No. 13-15). These parts are also characteristic with increased concentration of As. In the veins with sulphosalts at the locality Paurovská, it is the core of pyrite grains with concentric zoning, which are enriched with Au, Sb, Cu, As and also Se. According to spectral analyses, the sample of ore rocks with abundant pyrite from the Bruchatý Grúnik contains 0.18 ppm Au.

Chopec: Analyses No. 1-4 from the lightest phase to the darkest; pyrite in association with galenite, tennantite, quartz, ankerite, siderite and barite.

Helena: Analyses No. 5, 6 - light zones, 7, 8 - dark zones, 9 - very dark pyrite. Analyses No. 5-8 represents relatively large pyrite grains in arsenopyrite veins, analysis No. 9 represent pyrite that is part of Ni-Co-bearing mineral paragenesis.

Bruchatý Grúnik: Analyses No. 10, 11 - light zones, 12 - dark zone, idiomorphic pyrite in paragenesis with genetically younger galenite in quartz.

Paurovská: Analyses No. 13 - 15 of the zoned pyrite are ordered from the lightest phase to the darkest. Analysis No. 13 is the core of the grain and Analysis No. 15 is the edge of the grain. The pyrite originates from the quartz-sulphosalt phase of the mineralization.

Krutovite (?) $NiAs_2$ have been identified on the base of the optical properties and preliminary chemical analysis in association with galenite, tetrahedrite, arsenopyrite, chalcopyrite, Ni-Co-bearing minerals and pyrite on the sample from the locality Bruchatý Grúnik (Fig. 4).

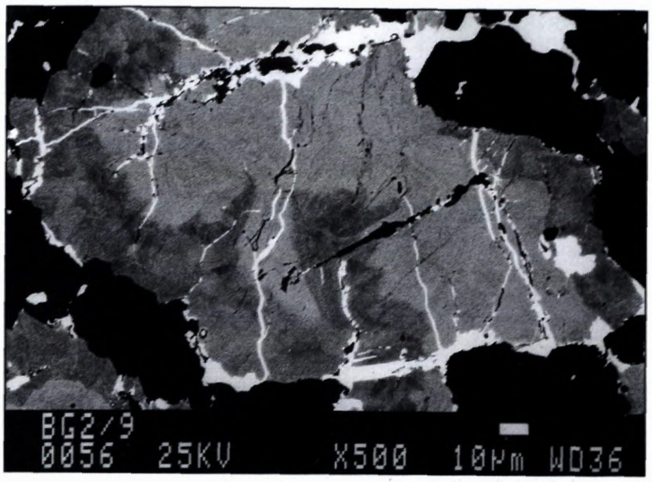


Fig. 4. Zoned krutovite (?) with galena veins (white) from the locality Bruchatý Grúnik.

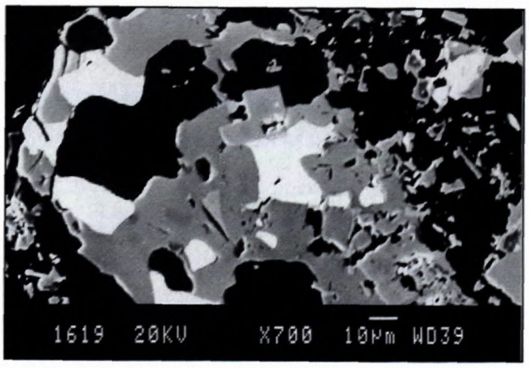


Fig. 5. Idiomorphic crystals of gersdorffite-(Co), (light-grey, cubic in centre), with galenite (white), tennantite (dark-grey) and tetrahedrite (light-grey, inclusion in the middle of the tennantite grain) from the locality Vyšná Boca - Helena.

Gersdorffite NiAsS, together with arsenopyrite, cobaltite, galenite, tetrahedrite, pyrite and Ni-bearing diarsenate, occur in carbonate-quartz-sulphide vein at the locality Bruchatý Grúnik. In SE part of the mining area Helena, the gersdorffite occurs in probably high-thermal arsenopyrite veins in association with cobaltite, arsenopyrite, pyrite, galenite, tennantite, carrollite and rare tetrahedrite. It creates idiomorphic crystals large up to 13 μm and with square or rectangular cross-section. Sometimes it forms hem around arsenopyrite aggregates. According to its chemical composition it resemble to gersdorffite-(Co) (Fig. 5). The average WDS analyses of gersdorffite-

Tab. 1. Electron microprobe analyses of pyrite from the Vyšná Boca area.

Σ	Starobocianska dolina - Chopec				H e l e n a					Bruchatý grúnik			P a u r o v s k á		
wt. %.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fe	45,37	45,4	45,63	45,44	45,62	45,61	44,76	44,48	39,26	44,96	45,58	46,06	44,67	46,61	46,27
As	0	0	0	0,55	1,04	1,19	1,17	1,31	0,4	1,24	1,41	0,47	2,13	0,78	0,22
Sb	0	0	0	0	0	0	0	0	0	0	0	0	0,37	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0	0	0,15	0,06	0,07
Co	0	0	0	0	0	0,04	0,16	0,11	4,81	0	0	0	0	0	0
Ni	0,01	0	0,02	0,01	0,12	0,15	0,35	0,38	1,55	0,04	0,24	0	0,01	0,05	0
Au	0	0,01	0	0,19	0	0,08	0,18	0	0	0	0	0,03	0,14	0	0
S	53,22	53,15	52,92	52,39	52,98	52,86	52,65	52,16	52,1	52,65	51,84	51,51	52,34	53,83	53,89
Se	0	0	0	0	0	0	0	0	0	0	0	0	0,15	0,02	0
Σ	98,6	98,56	98,57	98,58	99,76	99,93	99,27	98,44	98,12	98,89	99,07	98,07	99,96	101,35	100,45
								atom. %.							
Fe	32,86	32,9	33,11	33,13	32,87	32,87	32,47	32,52	28,8	32,67	33,24	33,83	32,4	33,04	32,96
As	0	0	0	0,3	0,56	0,64	0,63	0,71	0,22	0,67	0,76	0,26	1,15	0,41	0,11
Sb	0	0	0	0	0	0	0	0	0	0	0	0	0,12	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0	0	0,1	0,04	0,05
Co	0	0	0	0	0	0,03	0,11	0,08	3,35	0	0	0	0	0	0
Ni	0	0	0,01	0,01	0,08	0,1	0,24	0,27	1,08	0,03	0,16	0	0,01	0,04	0
Au	0	0	0	0,04	0	0,02	0,04	0	0	0	0	0,01	0,03	0	0
S	67,14	67,1	66,88	66,52	66,49	66,35	66,52	66,43	66,56	66,63	65,84	65,9	66,13	66,46	66,88
Se	0	0	0	0	0	0	0	0	0	0	0	0	0,07	0,01	0
Σ	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

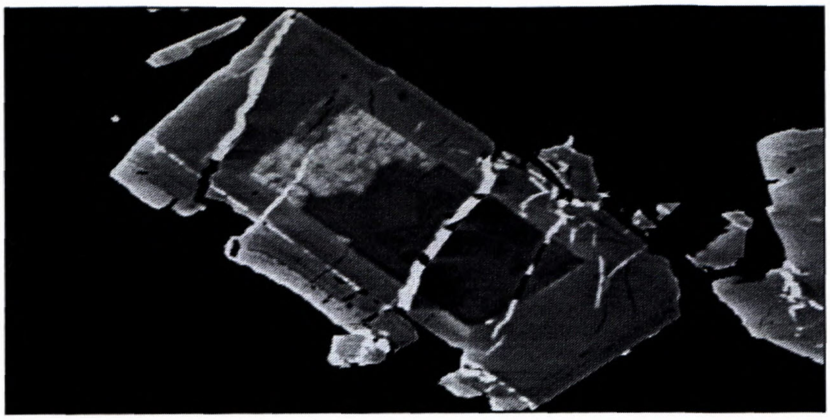
Tab. 2a. Electron microprobe analyses of arsenopyrite from the Vyšná Boca area.

	B r u c h a t ý g r ú n i k												
wt. %.	1	2	3	4	5	6	7	8	9	10	11	12	13
S	20,97	21,52	21,41	19,58	20,06	21,65	21,13	21,16	19,42	16,7	19,92	19,61	20,79
Fe	33,83	34,08	34,81	33,86	33,59	34,45	33,72	34,36	34,05	33,17	34,74	33,73	34,5
As	43,13	43,95	43,58	45,18	45,17	43,71	41,44	44,94	47,26	50,28	45,24	45,41	42,93
Co	0	0	0,01	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0,03	0,01	0,005	0,003	0,13	0,28	0,26	0,18	0,02	0
Sb	0	0	0	0,9	0,21	0	1,34	0	0	0	0	0	0
Au	0	0	0	0,07	0,03	0	0	0,02	0	0	0	0	0,01
Cu	0,77	0,37	0,39	0	0	0	0	0	0,06	0,06	0	0	0
Σ	98,7	99,92	100,2	99,62	99,07	99,82	97,63	100,61	101,07	100,47	100,08	98,77	98,23
							atom. %						
S	35,39	35,82	35,54	33,4	34,15	36	36,07	35,15	32,7	29,08	33,57	33,57	35,25
Fe	32,79	32,57	33,17	33,16	32,83	32,89	33,05	32,77	32,93	33,16	33,63	33,15	33,59
As	31,16	31,3	30,96	32,99	32,91	31,106	30,28	31,95	34,06	37,47	32,63	33,26	31,16
Co	0	0	0,01	0	0	0	0	0	0	0	0	0	0
Ni	0	0	0	0,03	0,01	0,005	0,003	0,12	0,25	0,25	0,17	0,02	0
Sb	0	0	0	0,4	0,09	0	0,6	0	0	0	0	0	0
Au	0	0	0	0,02	0,01	0	0	0	0	0	0	0	0
Cu	0,66	0,31	0,32	0	0	0	0	0	0,05	0,05	0	0	0
Σ	100	100	100	100	100	100	100	100	100	100	100	100	100

Tab. 2b. (continued)

	B r u c h a t ý g r ú n i k									H e l e n a		
wt. %.	14	15	16	17	18	19	20	21	22	23	24	25
S	20,87	18,25	20,29	18,69	20,13	17,69	19,25	19,05	18,57	19,28	19,05	19,51
Fe	34,13	33,54	33,34	33,7	33,85	32,77	32,56	32,14	32,03	34,43	33,59	34,33
As	45,21	46,09	44,6	46,56	45,86	36,94	37,12	37,38	36,18	46,47	46,93	46,93
Co	0	0,01	0	0	0	0	0	0	0	0,08	0,11	0,08
Ni	0,07	0	0	0,02	0,02	0,02	0,02	0	0,04	0,06	0,03	0,02
Sb	0	0	0,13	0,78	0	11,59	10,49	10,6	11,81	0	0	0
Au	0	0,004	0	0	0,03	0	0	0,18	0	0,04	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0,01	0
Σ	100,28	97,89	98,36	99,75	99,89	99,01	99,44	99,34	98,63	100,36	99,72	100,87
						atom. %						
S	34,87	31,89	34,66	32,12	33,99	31,95	34,01	33,82	33,411	32,67	32,57	32,86
Fe	32,73	33,64	32,68	33,26	32,83	33,98	33,02	32,76	33,092	33,49	32,96	33,21
As	32,33	34,46	32,6	34,25	33,15	28,55	28,07	28,41	27,861	33,7	34,33	33,84
Co	0	0,01	0	0	0	0	0	0	0	0,08	0,1	0,07
Ni	0,07	0	0	0,02	0,02	0,01	0,02	0	0,042	0,05	0,03	0,02
Sb	0	0	0,06	0,35	0	5,51	4,88	4,96	5,594	0	0	0
Au	0	0	0	0	0,01	0	0	0,05	0	0,01	0	0
Cu	0	0	0	0	0	0	0	0	0	0	0,01	0
Σ	100	100	100	100	100	100	100	100	100	100	100	100

Fig. 6. Zoned arsenopyrite (magnification 2400x) with galenite veins from the locality Bruchatý Grúnik. Dark zones (Tab. 2a, Analyses No. 14-18), light zone in the middle of the grain - arsenopyrite-(Sb), (Tab. 2b, Analyses No. 19-22).



(Co) (5 measurements): Ni 14.988, Co 13.104, Fe 6.538, Sb 0.004, Au 0.035, Cu 1.136, As 43.588, S 19,442, 98.835 wt.%.

Cobaltite CoAsS, together with pyrite, galenite, minerals of isomorphous tetrahedrite-tennantite series and another Ni-Co-bearing minerals, is rarely found in arsenopyrite veins at the Bruchatý Grúnik and tailing pile of the Zubau gallery. It is usually idiomorphic or hypidiomorphic and it has chemical zonality. It was identified optically and preliminary by EDAX (Co 27.25, Ni 5.27, Fe 7.89, As 35.76, S 23.82, 100.00 wt.%).

Marcasite FeS_2 (rhombohedron) occurs rarely in siderite mineralization in a form of very tiny grains in quartz. Sometimes it replaces pyrite, or it comes into existence by its recrystallisation. It was identified optically and preliminary by EDS analysis.

Arsenopyrite FeAsS, together with pyrite and Fe-To-bearing oxides is abundant in altered, strongly silicified zones, where it forms several mm thick veins and impregnation composed of heavily cataclastic, less idiomorphic grains at the edges of hydrothermal siderite veins. It is exceptional in siderite veins with quartz-sulphide mineral association, where it occurs as individual idiomorphic grains or in clusters in quartz together with chalcopyrite, tetrahedrite, pyrite, galena and sulphosalts. Ni-Co mineralization occurs in arsenopyrite veins with pyrite at the mining area Helena. Arsenopyrite sometimes has optical zoning, the most common zoning is the hourglass and sector zoning. At Bruchatý Grúnik, where it, together with Ni-bearing diarsenides, tetrahedrite and galenite, occurs in quartz-carbonate vein rocks it forms idiomorphic crystals with characteristic oscillate zoning. Later galenite veins often penetrate into idiomorphic arsenopyrite grains. Tiny inclusions of galenite are also often, mostly in centre of arsenopyrite crystals. It was identified optically with reflected light and by WDS (Tab. 2a, 2b). In Tab. 2a. (Analyses No. 1-3), there is idiomorphic zoned arsenopyrite within tetrahedrite. The measured zones are from the lightest (increased concentration of As) to the darkest phase (increased concentration of S). Similar zoning has arsenopyrite grains from the Analyses No. 4-6. The Analyses No. 14-22 (Tab. 2b) are analyses of very fine zoned arsenopyrite that is scattered in block quartz from brecciated fragments of a carbonate-sulphide vein. The lightest phase in the crystal centre is formed with arsenopyrite - Sb (the Analyses No. 19-22, Fig. 6). Arsenopyrite from the locality Bruchatý Grúnik contains up to 0.28 wt.% Ni, Co is not present at all. Arsenopyrite from the locality Helena contains up to 0.11 wt.% Co; Ni is presented only in 0.0X wt.%. In some cases we have measured increased concentration of Au by EDS (see Tab. 2).

Sulphosalts are represented in siderite veins by minerals of pavonite homologous series and isotype series of aikinite.

Sulphosalts of pavonite homologous series are represented by *benjaminite* ($Ag_3Bi_7S_{12}$) that exceptionally occurs together with chalcopyrite in veins within quartz. It forms segregate inclusions up to 10 μm large in sulphosalts, which are with their chemical composition similar to bismuthite and members of aikinite isotype series. Benjaminite is chemically homogeneous. It was identified by WDS analysis. Sulphosalts, according to their chemical composition resemble probably to *borodaevite* (?), were found at the locality Bruchatý Grúnik, where they form up to 1 mm large needle-shaped crystals within ankerite together with galena, chalcopyrite, tetrahedrite and another sulphosalts. Allotriomorphic grains are homogeneous. Mainly the needle-shaped crystals intergrow with galenite and another sulphosalts. These sulphosalts sometimes contains very tiny inclusions of galenite. They have been identified by electron microprobe. Their chemical composition is subject of next research.

Typical and for siderite veins of this area characteristic sulphosalts of aikinite isotype series are represented mainly by *lindströmite* ($Cu_3Pb_3Bi_7S_{18}$), *hammarite* ($Cu_2Pb_2Bi_{11}S_{18}$), *friedrichite* ($Cu_5Pb_5Bi_7S_{18}$), less *pecoite* (?) ($CuPbBi_{11}S_{18}$), *krupkaite* ($CuPbBi_3S_6$) and *aikinite* (?) ($CuPbBiS_3$). They are extended almost at all siderite or siderite-barite deposits between Vyšná Boca and Jarabá, however, mostly in microscopic sizes. Only in one tailing pile at the vein system Paurovská these sulphosalts occur also in form of individual needles, clusters and bush like formation that is large up to several cm and composed of light-grey needles. Sulphosalts occur in white-grey quartz in association with disseminated siderite crystals or small siderite clusters, pyrite, tetrahedrite and minerals of chalcopyrite group. Sulphosalts are the main ore minerals. At the other localities, the sulphosalts of aikinite isotype

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series occur usually in association with chalcopyrite, tetrahedrite and pyrite within white quartz or exclusively within barite as well (Kumštová dolina valley). The needles of the sulphosalts are up to 2 mm large, 0.5 mm thick and they are variably folded. Some of them form small inclusions in chalcopyrite or tetrahedrite, which are result of magmatic segregation. They have been identified with reflected light and by EMPA (Fig. 7).

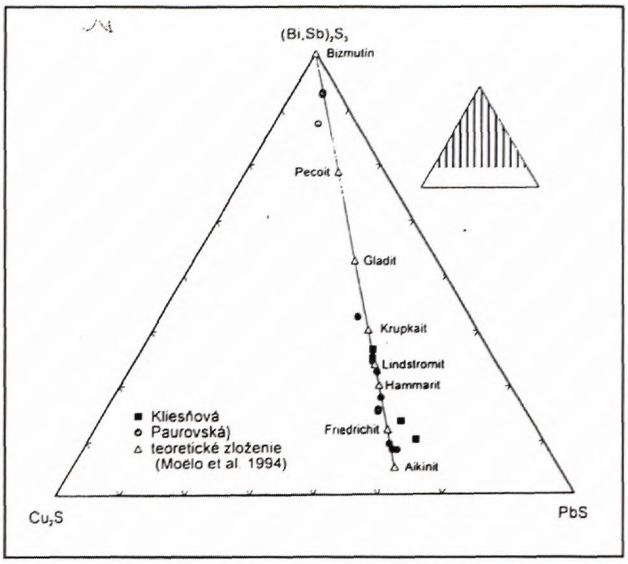

Fig. 7. Sulphosalts of aikinite isoseries from Vyšná Boca deposit..

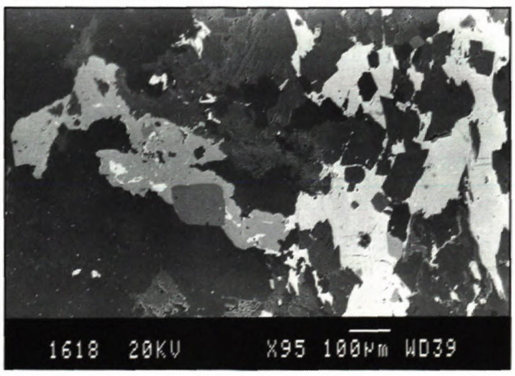

Fig. 8. Sulphosalts of bismuthite-aikinite series (light; in right half) with tetrahedrite (grey), pyrite (dark-grey, idiomorphic) and siderite (black-grey, allotriomorphic) in a quartz (black) from the locality Paurovská.

Tetrahedrite $Cu_{12}Sb_4S_{13}$ is the main ore mineral of the quartz-sulphide mineral association. It occurs in form of allotriomorphic, exclusively also as hypidiomorphic or idiomorphic aggregates, mainly in cracks and weakened zones within white quartz, rarely within carbonates and barite. It occurs individually or in clusters or grains together with chalcopyrite, pyrite, less with galena, sphalerite, arsenopyrite and Cu-Pb-Bi sulphosalts. Bruchatý Grúnik, the tetrahedrite forms compact mass large up to several cm². They are often intergrowth with galenite, sphalerite, less with Ni-bearing diarsenides. Sometimes it is replaced by chalcopyrite. On some aggregates of tetrahedrite oscillate chemical zoning can be observed. This is caused mainly by content of Sb, less by content of As, Cu and S. It contains inclusions of chalcopyrite, sphalerite, pyrite and galena, and it itself forms inclusions in metacrystals of pyrite. It has been identified optically with reflected light and by electron microprobe (Tab. 3a, 3b), and with help of reflectance curves (Fig. 9). In comparison to tetrahedrite from the Kumštová dolina valley (see Tab. 3a, analyses 1-3 and 9-11), the higher reflectance in tetrahedrite from the locality Paurovská is caused mainly by higher concentration of Bi, less by higher ratio of Sb:As with advantage to antimony. In Tab. 3b, there are analyses of zoned tetrahedrite (Analyses No. 16-22). They are ordered from the lightest to the darkest phase. The zoning is caused by variation of Sb and As concentration.

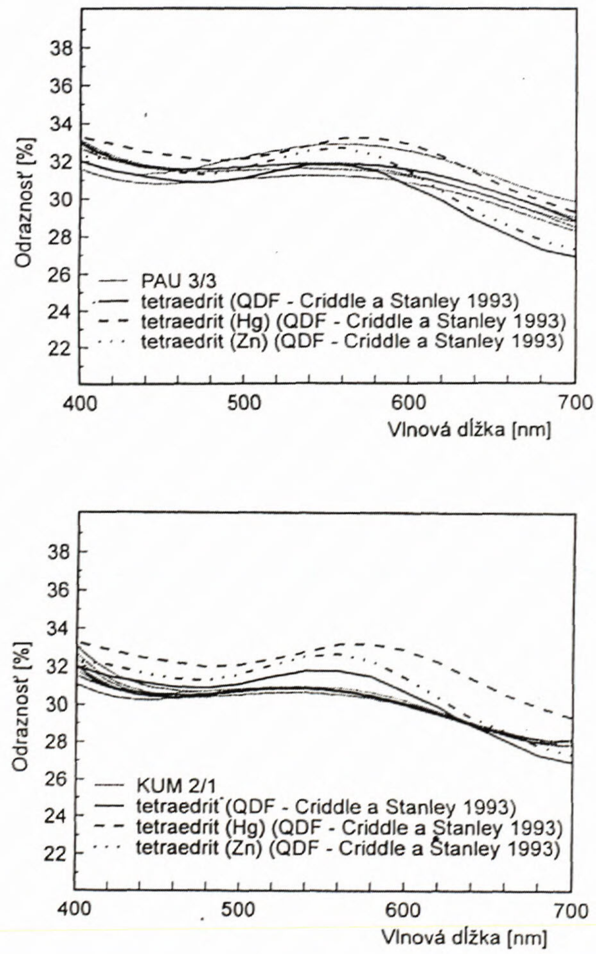

Fig. 9. Reflectance curves of tetrahedrite from the Vyšná Boca area (PAU 3/3 - Paurovská, KUM 2/1 - Kumštová dolina valley).

Tennantite $Cu_{12}As_4S_{13}$ occurs in the vicinity of Vyšná Boca only in arsenopyrite veins in the mining area Helena (Fig. 5), where it is in association with Ni-Co-bearing minerals, pyrite, galena, quartz and carbonates, and in the mineral deposit Chopec (Fig. 10). At Chopec, tennantite, together with siderite, barite and galena, is the most

Tab. 3a. Point electron microprobe analyses of tetrahedrite from the Vyšná Boca area.

	Paurovská			Kliesňová					Kumštová dolina			Králička			
wt. %	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cu	37,74	37,72	37,72	41,84	39,77	39,27	39,64	39,05	40,6	40,36	40,89	39,35	39,77	39,15	38,88
Ag	1,6	1,35	1,05	1,2	1,04	1,21	1,03	1,25	1,49	1,38	1,22	0,05	0,3	0,69	0,35
Fe	2,52	2,7	2,17	3,17	2,79	2,74	2,86	2,77	3,25	3,26	3,35	3,21	3,17	3,3	3,34
Zn	4,27	3,98	4,39	4,04	4,48	4,37	4,47	4,34	3,34	3,27	3,35	3,68	3,76	3,6	3,65
Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sb	25,72	25,37	25,75	19,12	18,57	18,64	19,28	19,19	19,4	19,62	19,04	23,14	22,79	22,84	22,3
As	0,75	0,89	0,8	5,37	6,9	6,64	6,13	6,44	6,05	6,48	6,44	4,7	4,79	4,73	5,07
Bi	3,16	3,21	2,64	1,24	0,53	0,49	0,41	0,97	0,44	0,2	0,59	0	0	0	0
S	24,99	25,04	24,97	22,82	26,17	26,27	25,96	24,6	25,86	26,21	26,32	25,55	24,96	24,91	24,72
Σ	100,8	100,26	99,49	98,8	100,3	99,63	99,78	98,61	100,4	100,8	101,2	99,68	99,54	99,22	98,31
atom. %.															
Cu	34,23	34,28	34,46	37,95	34,44	34,17	34,57	34,96	35,28	34,85	35,13	34,73	35,31	34,93	34,91
Ag	0,86	0,72	0,56	0,64	0,53	0,62	0,53	0,66	0,76	0,7	0,62	0,03	0,16	0,36	0,19
Fe	2,61	2,8	2,25	3,28	2,75	2,72	2,84	2,82	3,22	3,2	3,27	3,23	3,21	3,34	3,41
Zn	3,77	3,51	3,9	3,58	3,77	3,7	3,79	3,78	2,82	2,75	2,8	3,15	3,25	3,12	3,19
Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sb	12,17	12,03	12,28	9,05	8,39	8,46	8,77	8,97	8,8	8,84	8,54	10,66	10,56	10,64	10,45
As	0,57	0,69	0,62	4,13	5,07	4,9	4,53	4,89	4,46	4,75	4,69	3,52	3,61	3,58	3,86
Bi	0,87	0,89	0,73	0,34	0,14	0,13	0,11	0,26	0,12	0,05	0,15	0	0	0	0
S	44,92	45,086	45,2	41,02	44,91	45,3	44,86	43,66	44,54	44,86	44,8	44,69	43,91	44,04	43,99
Σ	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Tab. 3b. (continued)

	Bruchatý grúnik									Pod Štefanom				
wt. %	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Cu	37,15	37,78	37,88	38,75	37,95	38,42	38,83	32,9	32,48	34,09	39,15	39,22	39,27	42,4
Ag	2,04	1,37	1,76	1,57	1,71	1,79	1,46	7,38	7,79	6,41	0,8	1,04	1,17	1,85
Fe	2,2	2,2	3,03	3,38	2,84	3,32	3,51	2,42	1,9	1,94	3,34	3,33	3,25	3,42
Zn	4,95	5	4,26	3,74	4,28	3,67	3,71	5,25	5,32	5,5	3,23	3,23	3,37	2,82
Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sb	27,84	25,63	21,92	23,67	22,4	22,7	19,89	27,67	28,2	25,64	21,53	21,94	21,61	21,76
As	1,87	2,9	4,81	4,83	4,97	4,51	6,38	1,03	1,11	2,36	5,11	5,16	4,92	3,46
Bi	0	0	0	0	0	0	0	0	0	0	0,84	1,04	0,84	0,85
S	24,51	25,15	25,29	24,59	25,51	25,31	25,59	24,03	23,97	23,57	25,6	25,79	25,52	25,35
Σ	100,6	100	98,95	100,5	99,66	99,72	99,37	100,7	100,8	99,51	99,6	100,8	99,95	101,9
atom. %														
Cu	33,67	33,84	33,77	34,49	33,64	34,11	34,13	30,45	30,2	31,7	34,61	34,4	34,69	36,89
Ag	1,09	0,72	0,93	0,82	0,9	0,93	0,75	4,02	4,27	3,51	0,42	0,54	0,61	0,95
Fe	2,26	2,25	3,07	3,43	2,87	3,36	3,51	2,54	2,01	2,05	3,36	3,32	3,26	3,39
Zn	4,36	4,36	3,69	3,23	3,69	3,17	3,17	4,73	4,8	4,97	2,77	2,75	2,9	2,39
Hg	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sb	13,17	11,98	10,2	10,99	10,36	10,52	9,12	13,37	13,68	12,45	9,93	10,04	9,96	9,88
As	1,44	2,2	3,64	3,64	3,74	3,39	4,75	0,81	0,88	1,86	3,83	3,84	3,69	2,55
Bi	0	0	0	0	0	0	0	0	0	0	0,23	0,28	0,23	0,23
S	44,01	44,65	44,69	43,39	44,81	44,52	44,56	44,09	44,16	43,45	44,85	44,83	44,66	43,72
Σ	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Crystallochemical formula of tetrahedrite (recalculated to 16 cations)

1. $(Cu_{9.75}Ag_{0.25})_{10}(Cu_{0.19}Fe_{0.76}Zn_{1.09})_{2.04}(Sb_{3.54}As_{0.17}Bi_{0.25})_{3.96}S_{13.05}$
2. $(Cu_{9.79}Ag_{0.21})_{10}(Cu_{0.20}Fe_{0.82}Zn_{0.82})_{2.04}(Sb_{3.50}As_{0.20}Bi_{0.26})_{3.96}S_{13.14}$
3. $(Cu_{9.84}Ag_{0.16})_{10}(Cu_{0.22}Fe_{0.66}Zn_{1.14})_{2.02}(Sb_{3.59}As_{0.18}Bi_{0.21})_{3.98}S_{13.20}$
4. $(Cu_{9.83}Ag_{0.17})_{10}(Cu_{0.47}Fe_{0.89}Zn_{0.97})_{2.33}(Sb_{2.46}As_{1.12}Bi_{0.09})_{3.67}S_{11.13}$
5. $(Cu_{9.85}Ag_{0.15})_{10}(Cu_{0.15}Fe_{0.80}Zn_{1.10})_{2.05}(Sb_{2.44}As_{1.47}Bi_{0.04})_{3.95}S_{13.04}$
6. $(Cu_{9.82}Ag_{0.18})_{10}(Cu_{0.18}Fe_{0.80}Zn_{1.08})_{2.06}(Sb_{2.48}As_{1.43}Bi_{0.04})_{3.95}S_{13.25}$
7. $(Cu_{9.85}Ag_{0.15})_{10}(Cu_{0.18}Fe_{0.82}Zn_{1.10})_{2.10}(Sb_{2.55}As_{1.32}Bi_{0.03})_{3.90}S_{13.02}$
8. $(Cu_{9.81}Ag_{0.19})_{10}(Cu_{0.12}Fe_{0.80}Zn_{1.07})_{1.99}(Sb_{2.55}As_{1.39}Bi_{0.07})_{4.01}S_{12.40}$
9. $(Cu_{9.78}Ag_{0.22})_{10}(Cu_{0.40}Fe_{0.93}Zn_{0.81})_{2.14}(Sb_{2.54}As_{1.29}Bi_{0.03})_{3.86}S_{12.85}$
10. $(Cu_{9.80}Ag_{0.20})_{10}(Cu_{0.32}Fe_{0.93}Zn_{0.80})_{2.05}(Sb_{2.57}As_{1.38}Bi_{0.01})_{3.96}S_{13.01}$
11. $(Cu_{9.82}Ag_{0.18})_{10}(Cu_{0.36}Fe_{0.95}Zn_{0.81})_{2.12}(Sb_{2.48}As_{1.36}Bi_{0.04})_{3.88}S_{12.99}$
12. $(Cu_{9.99}Ag_{0.01})_{10}(Cu_{0.06}Fe_{0.93}Zn_{0.91})_{1.90}(Sb_{3.08}As_{1.02})_{4.10}S_{12.93}$
13. $(Cu_{9.96}Ag_{0.04})_{10}(Cu_{0.11}Fe_{0.91}Zn_{0.93})_{1.95}(Sb_{3.01}As_{1.03})_{4.04}S_{12.53}$
14. $(Cu_{9.90}Ag_{0.10})_{10}(Cu_{0.08}Fe_{0.96}Zn_{0.89})_{1.93}(Sb_{3.04}As_{1.02})_{4.06}S_{12.59}$
15. $(Cu_{9.95}Ag_{0.05})_{10}(Cu_{0.02}Fe_{0.97}Zn_{0.91})_{1.90}(Sb_{2.99}As_{1.10})_{4.09}S_{12.57}$
16. $(Cu_{9.62}Ag_{0.31})_{9.93}(Fe_{0.65}Zn_{1.24})_{1.89}(Sb_{3.76}As_{0.41})_{4.18}S_{12.58}$
17. $(Cu_{9.78}Ag_{0.21})_{9.99}(Fe_{0.65}Zn_{1.26})_{1.91}(Sb_{3.46}As_{0.64})_{4.10}S_{12.92}$
18. $(Cu_{9.73}Ag_{0.27})_{10}(Cu_{0.04}Fe_{0.89}Zn_{1.07})_{2.00}(Sb_{2.95}As_{1.05})_{4.00}S_{12.93}$
19. $(Cu_{9.75}Ag_{0.23})_{9.98}(Fe_{0.97}Zn_{0.91})_{1.88}(Sb_{3.11}As_{1.03})_{4.14}S_{12.27}$
20. $(Cu_{9.74}Ag_{0.26})_{10}(Cu_{0.01}Fe_{0.83}Zn_{1.07})_{1.91}(Sb_{3.00}As_{1.09})_{4.09}S_{12.99}$
21. $(Cu_{9.73}Ag_{0.27})_{10}(Cu_{0.11}Fe_{0.97}Zn_{0.91})_{1.99}(Sb_{3.03}As_{0.98})_{4.01}S_{12.84}$
22. $(Cu_{9.78}Ag_{0.22})_{10}(Cu_{0.07}Fe_{1.01}Zn_{0.92})_{2.00}(Sb_{2.63}As_{1.37})_{4.00}S_{12.86}$
23. $(Cu_{8.71}Ag_{1.15})_{9.86}(Fe_{0.73}Zn_{1.35})_{2.08}(Sb_{3.83}As_{0.23})_{4.06}S_{12.62}$
24. $(Cu_{8.65}Ag_{1.22})_{9.87}(Fe_{0.58}Zn_{1.38})_{1.96}(Sb_{3.92}As_{0.25})_{4.17}S_{12.65}$
25. $(Cu_{8.97}Ag_{0.99})_{9.96}(Fe_{0.58}Zn_{1.41})_{1.99}(Sb_{3.52}As_{0.53})_{3.85}S_{12.30}$
26. $(Cu_{9.88}Ag_{0.12})_{10}(Cu_{0.16}Fe_{0.97}Zn_{0.81})_{1.94}(Sb_{2.88}As_{1.11}Bi_{0.07})_{4.06}S_{13.01}$
27. $(Cu_{9.84}Ag_{0.16})_{10}(Cu_{0.13}Fe_{0.96}Zn_{0.80})_{1.89}(Sb_{2.91}As_{1.11}Bi_{0.08})_{4.10}S_{13.00}$
28. $(Cu_{9.82}Ag_{0.18})_{10}(Cu_{0.21}Fe_{0.94}Zn_{0.84})_{1.99}(Sb_{2.88}As_{1.07}Bi_{0.07})_{4.02}S_{12.92}$
29. $(Cu_{9.73}Ag_{0.27})_{10}(Cu_{0.76}Fe_{0.96}Zn_{0.68})_{2.40}(Sb_{2.81}As_{0.72}Bi_{0.07})_{3.60}S_{12.43}$

abundant ore mineral in the ankerite-quartz vein rock. In this vein, pyrite and exclusively also sphalerite and chalcopyrite are also present. Here the tennantite forms very tiny grains within quartz, or on the contrary, it forms large aggregates (up to 4 mm) and clusters together with idiomorphic pyrite, sometimes also with galenite within carbonates. It contains inclusions of pyrite and galena, and it itself forms inclusions and smaller rounded aggregates in galena. In the mining area Helena, the tennantite seldom contains inclusions of tetrahedrite. It has been identified optically with reflected light and by WDS analyses (Tab. 4).

Tab. 4 The electron microanalyses of tennantite from the Vyšná Boca area.

	Helena						Starobocianska dol.-Chopec				
wt. %.	1	2	3	4	5	6	7	8	9	10	11
Cu	43,23	42,36	42,72	41,87	41,81	42,09	42,51	42,38	42,62	43,1	42,5
Ag	0	0,23	0,17	0	0	0	0,3	0,16	0,26	0,11	0,23
Fe	6,01	5,84	5,92	6,12	6,11	6,09	3,14	3,27	3,28	3,34	3,26
Zn	0,24	0,19	0,3				4,54	4,43	4,59	4,38	4,4
Hg	0	0	0				0	0	0	0	0
Co				0,1	0,08	0,14					
Ni				0,08	0,07	0,11					
Au				0,17	0	0					
Sb	4,7	4,64	4,64	4,31	4,18	3,87	4,64	4,06	4,58	3,18	3,57
As	16,8	17,05	16,61	18,17	18,33	18,14	17,31	18,39	17,41	18,38	18,43
Bi	0	0	0				0	0	0	0	0
S	28,44	28,31	28	28,4	28,58	28,32	25,93	27,82	28,06	28,2	25,7
Σ	99,42	98,62	98,36	99,22	99,16	98,76	98,37	100,51	100,8	100,69	98,09
					atom. %.						
Cu	35,04	34,63	35,06	34,04	33,91	34,27	35,68	34,36	34,45	34,65	35,7
Ag	0	0,11	0,08	0	0	0	0,15	0,08	0,12	0,05	0,11
Fe	5,54	5,43	5,53	5,66	5,64	5,64	3	3,02	3,01	3,06	3,11
Zn	0,19	0,15	0,24				3,7	3,49	3,61	3,53	3,6
Hg	0	0	0				0	0	0	0	0
Co				0,09	0,07	0,12					
Ni				0,07	0,06	0,1					
Au				0,04	0	0					
Sb	1,99	1,98	1,99	1,83	1,77	1,64	2,03	1,72	1,93	1,34	1,57
As	11,55	11,83	11,56	12,53	12,61	12,53	12,32	12,64	11,93	12,53	13,13
Bi	0	0	0				0	0	0	0	0
S	45,69	45,87	45,54	45,75	45,93	45,7	43,12	44,7	44,94	44,94	42,78
Σ	100	100	100	100	100	100	100	100	100	100	100

Crystallochemical formula of tennantite: (recalculated to 16 cations).

1. $Cu_{10}(Cu_{0.32}Fe_{1.63}Zn_{0.06})_{2.01}(As_{3.40}Sb_{0.59})_{3.99}S_{13.46}$
2. $(Cu_{9.97}Ag_{0.03})_{10}(Cu_{0.27}Fe_{1.61}Zn_{0.04})_{1.92}(As_{3.50}Sb_{0.58})_{4.08}S_{13.56}$
3. $(Cu_{9.98}Ag_{0.02})_{10}(Cu_{0.33}Fe_{1.62}Zn_{0.07})_{2.02}(As_{3.40}Sb_{0.58})_{3.98}S_{13.38}$
4. $Cu_{10}(Cu_{0.04}Fe_{1.67}Co_{0.03}Ni_{0.02}Au_{0.01})_{1.77}(As_{3.69}Sb_{0.54})_{4.23}S_{13.49}$
5. $Cu_{10}(Cu_{0.04}Fe_{1.67}Co_{0.02}Ni_{0.02})_{1.75}(As_{3.73}Sb_{0.52})_{4.25}S_{13.60}$
6. $Cu_{10}(Cu_{0.10}Fe_{1.66}Co_{0.04}Ni_{0.03})_{1.83}(As_{3.69}Sb_{0.48})_{4.17}S_{13.47}$
7. $(Cu_{9.96}Ag_{0.04})_{10}(Cu_{0.08}Fe_{0.84}Zn_{1.04})_{1.96}(As_{3.47}Sb_{0.57})_{4.04}S_{12.13}$
8. $(Cu_{9.94}Ag_{0.02})_{9.96}(Fe_{0.87}Zn_{1.01})_{1.88}(As_{3.66}Sb_{0.50})_{4.16}S_{12.93}$
9. $(Cu_{9.97}Ag_{0.03})_{10}(Cu_{0.05}Fe_{0.87}Zn_{1.05})_{1.97}(As_{3.47}Sb_{0.56})_{4.03}S_{13.06}$
10. $(Cu_{9.99}Ag_{0.01})_{10}(Cu_{0.08}Fe_{0.89}Zn_{1.00})_{1.97}(As_{3.64}Sb_{0.39})_{4.03}S_{13.06}$
11. $(Cu_{9.97}Ag_{0.03})_{10}(Cu_{0.01}Fe_{0.87}Zn_{1.01})_{1.89}(As_{3.67}Sb_{0.44})_{4.11}S_{11.96}$

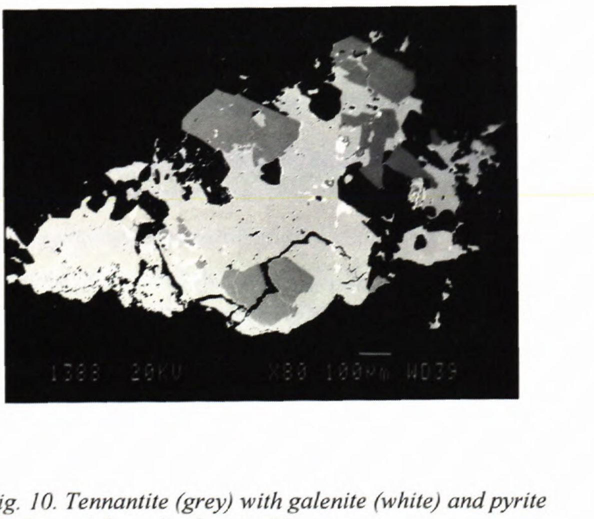

Fig. 10. Tennantite (grey) with galenite (white) and pyrite (dark-grey) from the deposit Chopec

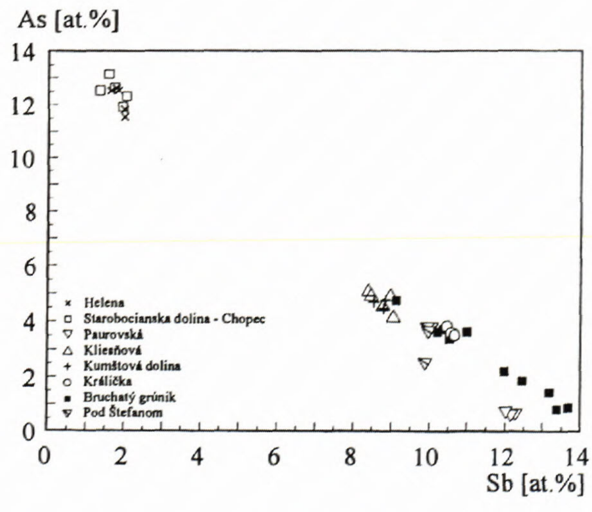

Fig. 11. As - Sb relationship in minerals of tetrahedrite - tennantite series from the Vyšná Boca area.

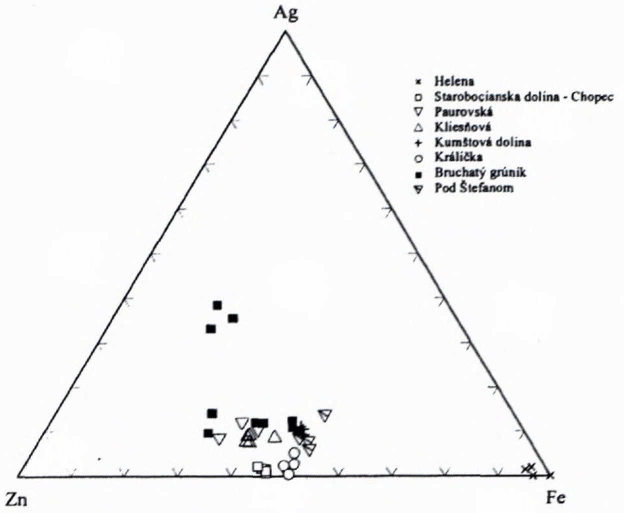

Fig. 12. Triangular diagram of Ag-Zn-Fe-bearing tetrahedrite-tennantite from the Vyšná Boca area.

Hematite Fe_2O_3 usually occurs in thin, practically monomineralic little veins composed of fine flaky variety of specularite. Specularite forms flakes and lamellas large 13 mm. The little veins are abundant in surrounding rocks and in ore vein where they transect all other types of mineral associations. Hematite is more abundant in barite-rich veins then in typical siderite-quartz veins with sulphide. In the locality Bruchatý Grúnik it forms little black veins composed of very tiny hematite micro-crystals in association with idiomorphic pyrite with hexahedron habit. The hematite was identified optically with reflected light and by EDAX.

Quartz (SiO_2) is abundant mineral in all mineral deposits in vicinity of Vyšná Boca. In siderite ore veins with quartz-sulphide mineralization it forms two generations: the older quartz is subtranslucent and forms up to 5 mm large mineral fragments in fine-grained siderite. The younger quartz is usually milky-white, more idiomorphic then the older and has sulphide mineralization in cracks (mainly tetrahedrite, chalcopyrite and pyrite). It forms veins usually 15 mm thin in coarse-grained siderite with which it often form combed intergrowth. At the siderite-barite deposit Pod Štefanom it often forms two generations. The older is coarse-grained quartz and the younger is fine-grained inlaid quartz that is intergrowing with carbonates. At the end of Kumštová dolina valley the quartz often forms idiomorphic hexahedral up to 4 cm long and 8 mm thick white crystals grown perpendicularly on base rock. Quartz is also a main mineral containing sulphosalt-carbonate fill on locality Paurovská. In quartz-carbonate-sulphide veins with abundant ankerite (the locality Bruchatý Grúnik and deposit Chopec) quartz forms several generations. The different quartz generations mutually differ not only by structure features, but also by content and quality of different sulphide and sulphosalts, colour, light transmissivity, mineral morphology etc. The quartz was identified optically and by X-ray diffraction analyses as subsidiary mineral during analyses for carbonate and barite.

Siderite ($FeCO_3$) is very abundant and dominant carbonate in most of carbonate-quartz-sulphide veins. Siderite has light brown to dark-brown colour, it is opaque with dull luster and fine to coarse-grained. The grain size is in range from 0.X - 18 mm. Siderite, together with quartz, barite, pyrite, chalcopyrite, tetrahedrite and sulphosalts of aikinite isoseries, occur in siderite veins. In ankerite veins it forms up to 1.5 cm thick veins filling and noddles and is associated with ankerite, quartz, galena, pyrite and tennantite. Siderite usually contains only very little sulphide relatively to content of quartz and barite. The highest concentration of disseminated sulphide is in fine-grained siderite (Bruchatý Grúnik, Pod Štefanom). There is almost none disseminated sulphide in coarse-grained siderite vein (Paurovská-Rovienky vein system). Sometimes, in fine-grained siderite, there is usually almost monomineralic idiomorphic pyrite (hexahedron, pentagonal dodecahedron). Siderite often cements rock and mica fragments at smaller occurrences (Nižná Helena, Banica, Podvrch). In siderite-barite deposits (Pod Štefanom, Kumštová dolina valley, Králička) siderite is often oxidised. Siderite was identified optically with transmitting and reflected light and also by DTA, X-ray diffraction analyses and manometry analyses (Tab. 5). These analyses suggest that more abundant members of siderite-magnesite isomorphous series are those with higher content of iron (siderite, sideroplesit). Tab. 5 does not include percentage content of CaO and MnO, because the contents were under the detection limit of the used manometry analyses and thus they are included into content of FeO. In insoluble residue of manometry analyses of carbonates we have identified mainly quartz (about 99 % in average), and accessory amounts of various micas (mostly muscovite), chlorites, rock fragments and unidentified grains, which proves that siderite veins have brecciated structure where framework of small siderite veins cements fragments of rocks and minerals. In samples No. 7, 8, 9 and 11 there was increased amount of grains of ore minerals (about 0,5 - 3 %). In the insoluble residue there were these ore minerals: chalcopyrite, tetrahedrite and pyrite that was dominant over other minerals in the sample No. 9.

Calcite $CaCO_3$ was found only in one sample from Bruchatý Grúnik, where it forms up to 1.4 mm large grains composed of white to grey-white rhombohedron crystals. The calcite, together with dolomite, form clusters in siderite, which are intersected with ankerite veins. It was identified optically with transmitting light and by EDS analysis.

Ankerite, $CaFe(CO_3)_2$, occurs rarely in studied area. It is abundant at Bruchatý Grúnik, where often coarse-grained white ankerite forms up to 3 cm thick veins penetrating through siderite and quartz veins. In most siderite veins the ankerite occurs in–rare small veins within siderite and quartz. At the locality Chopec, there are quartz-ankerite veins, where ankerite occurs in association with siderite, galena, tennantite and pyrite. In places coarse-grained ankerite dominates over quartz. In such places the hypidiomorphic ankerite phenocrysts are up to 2 cm large. The ankerite was preliminary identified by

Tab. 5. The results of manometry analyses of siderite from the Vyšná Boca area.

	Kliesňová		Helena	Paurovská				Kum. dol.	Pod Štefanom		Chopec
Analysis No.	1	2	3	4	5	6	7	8	9	10	11
FeO	52,27	55,66	58,02	60,71	54,97	59,54	57,66	62,01	46,62	51,44	55,72
MgO	6,12	3,73	3,08	1	5,43	1,91	3,36	0	8,23	5,86	4,85
CO_2	41,61	40,61	38,9	38,29	39,6	38,55	38,98	37,99	45,15	42,7	39,43
$(Fe,Mg)CO_3$	91,95	96,18	96,58	96,48	75,4	92,1	69,77	78,6	95,2	95,55	96,3
Insoluable r.	8,05	3,82	3,42	3,52	24,6	7,9	30,23	21,4	4,8	4,45	3,7
Carbon.mem.	sidpl.	sidpl.	sid.	sid.	sidpl.	sid.	sid.	sid.	pis.	sidpl.	sidpl.

measurement of refractive index, and by DTA and manometry analyses (locality Pod Štefanom: CaO 14.78, (FeO+MnO) 25.99, CO_2 40.81, $CaFe(CO_3)_2$ 92.97 wt.%, insoluble residue 8.03 wt. %).

Dolomite $CaMg(CO_3)_2$ is very rare in siderite deposits. It was found only in one sample from the locality Bruchatý Grúnik where 2 mm large black-grey dolomite crystals form grains with calcite and tiny ankerite veins within siderite. Part of the dolomite has increased concentration of FeO, which classifies it among Fe-bearing dolomite members. The dolomite is probably coloured with graphite pigment. The dolomite was identified by EDAX.

Kutnohorite (?) $CaMn(CO_3)_2$ was found only in one sample from the locality Kliesňová, where it forms 4 mm thick vein within siderite. It was identified by X-ray diffraction analysis (Tab. 6.). The table shows up, that it is carbonate from dolomite isomorphous series. The values of interlamellar distance (b) do not match the table values of dolomite, ankerite or kutnohorite, however, they are very close to them. This means, that it is member with strong isomorphism, and according to JCPDS tables (Berry ed., 1974) the values of interlamellar distances are nearest to member kutnohorite-(Mg).

Barite $BaSO_4$ is abundant mainly in northern vein area (end of the Kumštová dolina valley, Králička and the deposit Pod Štefanom), where it often intergrow with oxidised siderite and less often with quartz in association with chalcopyrite, tetrahedrite, pyrite and galena. It is rare in the southern vein system Paurovská - Rovienky and at Bruchatý Grúnik, where white barite forms mostly thin and short veins within gneisses, or it intersects older coarse-grained siderite and milky-white quartz with sulphides. Barite occurs as tiny grains in quartz-ankerite veins with galenite and tennantite (± pyrite, chalcopyrite) at the deposit Chopec in Starobocianska dolina valley. Macroscopically it is usually fine-grained, only in Kumštová dolina valley and Králička it is also compact. The colour of the barite is white, only at localities where it is abundant it has also pink, grey, brownish and yellowish colour. Barite from Králička and Paurovská has sometime bright-green luminescence under a ultraviolet lamp. The luminescent colours form streak and diffusion structures. It was identified by X-ray diffraction analysis (locality Pod Štefanom: 4.34 (33), 3.90 (40), 3.579 (40), 3.442 (100), 3.3198 (85), 3.103 (98), 2.839 (45), 2.731 (50), 2.122 (83), 2.109 (83)) and with help of refraction index. (Np = 1.623, Ng = 1.643; Paurovská).

Tab. 6. X-ray powder diffraction analyses of kutnohorite-(Mg) from the Vyšná Boca area.

dtab	Itab	d	I
5,41	2		
		4,267	2 Q
3,73	8	3,722	7
		3,349	8 Q
2,91	100	2,91	100
2,701	2	2,696	2
2,564	2		
2,423	6	2,421	5
2,209	10	2,205	11
2,031	6	2,026	7
1,862	4	1,858	3
1,823	10	1,82	12
1,804	12		
1,8	10	1,799	12
1,578	2		
1,556	4	1,552	4
1,512	2	1,507	1
1,477	4	1,474	3
1,457	2	1,454	3
1,445	2		
1,398	2	1,396	3
		1,348	3
1,309	2		
1,2816	2	1,2799	2
		1,2456	2
1,2071	2		
1,1799	2	1,1776	2
1,1524	2		
1,1328	2		
1,1176	4	1,1149	3

Schorl (?), $NaFe_3Al_6Si_6O_{18}(BO_3)_3(OH)_4$ was found only in one sample from Čertovica (under Rovienky), near a place where siderite veins crop out. About 2 cm large black tourmaline with vertical striation was embayed into white quartz. It was identified only visually.

Secondary minerals

Covellite CuS occurs in siderite veins rarely, but regularly. It is more common at the locality Pod Štefanom, where it occurs in chalcopyrite and tetrahedrite together with galenite and secondary Cu and Fe-bearing minerals (Fig. 13). It forms only very tiny, microscopic grains usually in chalcopyrite or tetrahedrite. It was identified with reflected light and preliminary by EDAX.

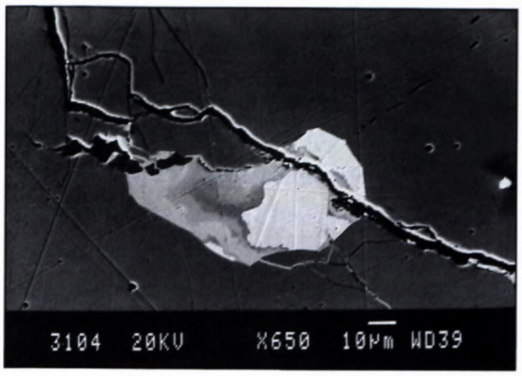

Fig. 13. Covellite (the darkest zone) with secondary Cu-bearing minerals and galena (white) in tetrahedrite (black-grey) from the deposit Pod Štefanom.

Goethite α-FeO(OH), together with another Fe-bearing oxides and hydroxides, is omnipresent mineral in siderite deposits and occurrences. It is part of oxidised zones, where it is product of weathering of carbonates, mainly siderite. Crystalline crust up to 0.8 mm thick occurs mainly on tailing pile of the gallery Vyšná Helena at the end of Kumštová dolina valley. It often has film, mamillary, radiolitic and crustal forms. It was identified optically with transmitted and reflected light.

Fe-bearing hydroxides are very abundant and regular companion of Fe-bearing carbonates in ore veins. They intensively replace mainly siderite, but also ankerite, pyrite, chalcopyrite (Fig. 14) and less tetrahedrite. They often penetrate along planes of cleavage of siderite and often fill narrow fissures and cracks in quartz. Skeleton, netted, bushy, finger-like and film structures are the most abundant grain shapes of all they have. They were identified optically with reflected light and by EDS analyses.

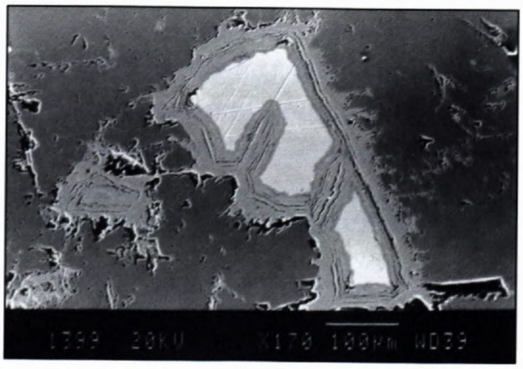

Fig. 14. Hydroxides of iron intensively replacing chalcopyrite, the Vyšná Boca area.

Aragonite $CaCO_3$ was found in the gallery Helena, where it forms clusters of tiny crystals spread over area several cm^2. Up to 1 mm large transparent crystals of aragonite have glassy luster, needle-shaped habit and usually grow on coarse-trained siderite. At the other siderite localities the aragonite is abundant and forms thick milky-white to pinkish-white film and thin crusts. It was identified optically and by X-ray diffraction analyses (Tab.7). In reaction with HCl it fizzles and dissolves.

Tab. 7. X-ray powder diffraction analyses of aragonite from the Vyšná Boca area.

dtab*	Itab*	d	I
4,212	2	4,29	17
		4,27	19
3,396	100	3,36	100
		3,33	52
3,273	52	3,28	42
		3,03	7
2,871	4	2,88	18
2,73	9	2,81	10
2,7	46	2,71	43
2,481	33	2,49	35
2,409	14	2,41	9
2,372	38	2,37	32
2,341	31	2,34	34
2,328	6	2,33	34
2,188	11	2,19	19
2,106	23	2,1	44
1,977	65	1,981	68
1,882	32		
1,877	25	1,877	31
1,814	23	1,824	11
1,759	4	1,755	15
1,742	25	1,738	16
1,728	15		
1,698	3	1,701	4

**-Berry (ed.)(1974)*

Azurite $Cu_3(CO_3)_2(OH)_2$ occurs together with malachite and another yet not identified secondary Cu-bearing minerals and Fe-bearing hydroxides in oxidised zone of siderite deposits. It occurs relatively more often at the deposit Pod Štefanom and in the lowest levels of the end of Kumštová dolina valley. Usually it occurs in a form of thin firm and crystalline crusts, rarely it forms 0.8 mm large translucent deep-blue crystals freely grown on weathered siderite or in voids in limonite. Sometimes it forms fluidic crystalline structure. It was identified optically and by morphology of the crystals.

Malachite $Cu_2(CO_3)(OH)_2$ often occurs together with another secondary Cu- and Fe-bearing minerals in oxidised zone of iron ore deposits and occurrences of the Vyšná Boca area. It forms usually thin firms or pulverulent aggregates. Malachite from these localities has characteristic green colour without significant light- or deep-green shade. It was identified optically and by EDAX.

Pharmacosiderite $KFe_4(AsO_4)_3(OH)_4.6H_2O$ is very rare. It was found near the surface where mylonite zone crops out of the mountain ridge Rovienky. Here farmakosiderite forms very tiny grey-green to yellow-green crystals grown on goethite. It occurs in voids and cracks of yellow-brown to brown quartz together with ferisymplezite and Fe-bearing hydroxides. It was identified by EDAX.

Ferisymplesite $Fe_3(AsO_4)_2(OH)_3.5H_2O$ is rarely found on the mountain ridge Rovienky in the crops out of mylonite zones. It forms film, collomorph and colloidal brown aggregates grown on goethite, less on farmakosiderite. It occurs in voids and cavities of limonite. It is similar to opal, evansite or metahalloysite. X-ray amorphous ferisymplesite was identified by EDS analysis.

In the Kumštová dolina valley we have found malachite and azurite together with olive-green firms and crystalline earthly aggregates containing Cu, Sb, Fe and less As. This miscellany of minerals comes to existence probably as secondary products of weathering of tetrahedrite. It was identified by EDAX.

Ore textures

Cocarde and mainly brecciated textures are the most common in siderite mineral deposits with quartz-sulphide mineral association. The genetically oldest quartz is disseminated in fine to medium-grained siderite, together with pyrite and another sulphides, muscovite (sericite) and chlorite. Siderite often cements rock fragments, as well as pieces of altered rocks. Coarse-grained siderite, together with younger quartz, has combed textures. In a sulphosalt vein at the locality Paurovská, rarely grey-white quartz containing disseminated siderite, sulphides and mainly sulphosalts envelope and enclose fragments of altered rocks as well as coarse-grained siderite that is combed intergrown with black-white quartz. Several mm-large clusters of often idiomorphic siderite crystals disseminated in quartz gives to veins here and there noddle character. Finger-like intergrowth of siderite and barite can be observed at the mineral deposit Pod Štefanom. In Kumštová dolina valley, sometimes barite, together with hematite, siderite, rarely also with quartz, form banded textures. At Králička and at mining area Eduard, barite is often massive and compact. Barite from monomineral barite vein at Chopec has coarse-crystal character. Quartz-ankerite vein with galenite and tennantite from the mineral deposit Chopec has brecciated textures at the places where fragments of siderite, ankerite and sometimes also altered rocks are enclosed in quartz. Galena with tennantite forms disseminated textures here. Quartz of several generations can be observed here. Cavities with tiny quartz crystals in the gallery Helena and barite in access gallery SW from the cottage Barbora at Vyšná Boca have drusy character. Sulphides in siderite deposits and occurrences occur in a form of veins and impregnation or they are einsprengled into carbonates, quartz and barite. Sometimes they form skin around quartz and ankerite grains.

The Mineralization Development

Several mineral paragenetic associations are distinguished within the siderite mineralization. They are ordered from the oldest to youngest ones, however, their age relations are not always proved enough.

1. The oldest evidence of hydrothermal mineralization in the studied area is the intensively silicified zones with arsenopyrite veins and disseminated pyrite. The siderite veins are strictly delimited from the hydrothermal altered zones or the thin siderite veins penetrate more or less into the silicified rocks. We incorporate into this phase the arsenopyrite veins with pyrite and Ni-Co-(Cu) mineralization of the adjacent rocks of siderite veins from the locality Helena. The position of quartz-tourmaline mineral association (Čertovica) has not been solved yet. With respect to the fact that it occurs in siderite deposits or in their neighbourhood, for instance Mýto pod Ďumbierom – Hviezda south (Majzlan and Chovan, 1997), it is probable that it is one of the siderite mineralization phase.

2. The siderite phase is represented by siderite veins with younger quartz-sulphide mineral association. The sulphides (pyrite, chalcopyrite, and tetrahedrite) form the thin veins in the milky-white quartz. Typical characteristics of the veins are coarse-grained and medium-grained siderite, thin oxidation zone (sometimes is missed) and the typical comb intergrowth of quartz and siderite. The three characteristic generation are distinguished: the oldest fine crystalline siderite I cementing the quartz fragments (probably rocky one) and the fragments of the altered rock. The main mass of siderite II is formed by coarse-grained and medium-grained, less fine-grained siderite. The youngest siderite III forms less occurred short thin veins that cross the previous two generations of siderite. These thin veins themselves can form several generations.

3. In the second phase the quartz-sulphosalt vein (Paurovská) was probably formed. The typical properties of this vein are sulphosalts and carbonates occurrences in the scattered form (disseminated textures) in grey-white and grey quartz. Except of the typical mineral composition some minerals have the specific chemical composition (for instance – tetrahedrite) that is different from minerals occurred in other carbonate-quartz-sulphide veins. Breccia fragments of quartz and siderite comb intergrowth from the previous phase are in the main quartz vein rocks.

4. In the third phase the younger siderite-barite veins were formed that are different from siderite ones of the first phase because of having more of barite component and sulphides occur more-less in noddle forms. Siderite form two main generations: siderite I is older than all other types and barite generations, and siderite II forming thin veins is younger than all barite types. The age relation between older and younger siderite veins in the Nízke Tatry Mts. was pointed out by Turan (1962) who distinguished the different concentrations of Sr in barite of various veins.

5. In the fourth phase the quartz-ankerite vein was probably formed with the younger galena-tennantite paragenesis in Chopec. This vein is characterised by plenty of quartz and pyrite types. It is younger than siderite veins because it encloses the fragments of older siderite. It occurs in granitoid rocks.

6. The youngest one in the area, in accordance with the present knowledge (Chovan et al., 1995 etc.), is the hematite mineralization where the hematite veins intersects all the previous types of ore mineralization. The similarities in age have the thin siderite veins interfering into Lower Triassic Lužnianske layers near Kumštové sedlo pass.

7. In the supergene phase were formed mainly Fe-bearing hydroxides for instance goethite (Helena, Kumštová dolina valley, Králička), less the Cu-bearing secondary minerals - malachite and azurite (Pod Štefanom, Kumštová dolina valley, Králička) and rarely Fe-bearing arsenates (Rovienky). The most abundant carbonate is the supergene aragonite that forms films in all the siderite deposits.

Discussion

Papp (1919) collected the first complete data about the iron ore in the Vyšná Boca area. By field and laboratory investigation we have found that the data about iron ore occurrences in the Vyšná Boca area (names, location and characteristics of the old mine works) as well as the analyses published in Papp´s work do not correspond with the present knowledge, Zoubek (1951) noted already that fact.

From the carbonates on hydrothermal veins siderite is the most abundant one (variety sideroplesite, pistomesite) that significantly prevails in the majority of deposits and occurrences over carbonates of dolomite-ankerite series. From the chemical composition of the carbonates of siderite-magnesite series of the different phases of siderite mineralization is obvious that in all types of siderite veins the quantitative composition of individual members of the series is almost the same. The calcite almost does not occur in siderite veins. It was found just in one sample in Bruchatý Grúnik in paragenetic association with dolomite, ankerite and siderite. The quantitative occurrence of the various carbonates and their chemical composition is very similar to the carbonates of siderite ore mineralization in the Spišsko-gemerské rudohorie Mts. (Cambel and Jarkovský, ed., 1985).

The gold presence in siderite veins was not confirmed (Maderspach, 1880; Toth, 1982). The occurrence of the free gold is not supposed in this type of mineralization.

The chemical composition of arsenopyrite from Vyšná Boca is the same as in other hydrothermal deposits in the Západné Karpaty Mts. (see Stankovič, 1998 etc.). At the locality Bruchatý Grúnik the arsenopyrite occurs rarely, it contains up to 11,6 wt. % Sb (Tab 1, analysis no 19-22). Similar type of arsenopyrite is sometimes gold bearing. The gold is probably fixed in lattice of arsenopyrite (Andráš et al., 1993). According to our investigation its distribution is random in arsenopyrite crystals. The connection of the "invisible" gold with zones rich in As and poor in S and Sb was not confirmed (Andráš et al. 1993).

The pyrites from the various veins have in siderite mineralization almost the same chemical composition. However, many of pyrite grains have chemical zoning. The zoning is caused by variation of Fe and S concentrations, sometimes by addition of subsidiary elements, mostly As. Central parts of concentric zoned grains exposed to reflected electrons have the lightest colours of all zones because they are enriched with subsidiary elements (Ni, Co, As, Cu, Sb, Au). Papers concerning the presence of "invisible" gold in zoned crystals of pyrite and arsenopyrite with Sb content in general was published by Andráš and Ragan (1994).

The chemical composition of tetrahedrite from carbonate-quartz-sulphide veins is relatively stabile. Different chemical composition has tetrahedrite from quartz - sulphosalt vein at Paurovská (it contains up to 3,21 wt. % Bi and max. 0,89 wt. % As). Tetrahedrite found in Rišianka in the Nízke Tatry Mts. (Majzlan et al. 1998) has similar Sb/As ratio. From the other localities the zero content of Bi in tetrahedrite (with typical intensive chemical zoning) from the locality Bruchatý Grúnik is exceptional. The contents of Ag in tetrahedrite from various veins are relatively stabile and vary in range 0,80 – 2,04 wt. % , average 1,38 wt. %. It is similar like in the Magurka deposit (Chovan et al., 1995). Higher concentration of silver in Ag-bearing tetrahedrite we have found only in one sample from the locality Bruchatý Grúnik (Tab. 6b, analyses no 23-25). This type of tetrahedrite contains 7,79 wt. % Ag.

By investigating the chemical composition of tennantite from two localities in the Vyšná Boca area (locality Helena – arsenopyrite veins with Ni-Co mineralization and locality Chopec–south – quartz-ankerite vein with galena and tennantite) we have found out that tennantite of both generations have practically identical chemical composition. The difference is only in Fe and Zn ratio. Tennantite from Ni-Co mineralization is characterised by intensive deficit of Zn due to Fe enrichment (average content of Fe 5,92 wt. %). Tennantite from both sites contain up to 0,3 wt. % Ag, zero content of Bi is typical for them. The whole area is characterised by absolute absence of Hg in minerals, which was expressed mainly in minerals of tetrahedrite group in which Hg does not occur even in trace amounts. Bi occurrences are interesting. In hydrothermal veins where galena, beside tetrahedrite or tennantite, is the main sulphide mineral, minerals of the tetrahedrite group do not contain Bi.

The comparisons of chemical composition of galena in association with arsenopyrite and with galena in association with tetrahedrite and sphalerite have revealed that the chemical compositions of both galenas of siderite mineralization are identical.

From the secondary minerals except of hydroxides of iron abundant crystalline films of aragonite were formed. Secondary minerals of copper are relatively rare comparing to amount and size of siderite localities. Forming of thin oxidised zones that are even missed on some localities probably causes their rare occurrence.

In altered zones that have not been deeply studied yet, the silicification, less sericitication and chloritization are extensive around quartz-sulphide veins. Close to ore veins there are almost totally silicified zones, in which arsenopyrite veins, rarely little grains of pyrite and sometimes plentiful Fe-Ti-bearing oxides occur. Gradually with increasing distance from an ore vein content of arsenopyrite decreases and content of free disseminated pyrite and other minerals increases. In the neighbourhood of siderite veins the close-ore metamorphosis reach max. first decades of cm, usually the thickness of altered rocks is lower.

On the base of mineralization development investigation we suppose that the oldest siderite veins are of Variscian age, while some, mainly younger generations of siderite (Černyšev et al., 1984; Chovan et al., 1996), could be the products of Alpine remobilisation. While in other parts of the Nízke Tatry Mts. the galena ore mineralization is related to barite rich ore veins (Jasenie – Soviansko, Malužiná – Olovienka etc.), in the Vyšná Boca area it is related to carbonate-quartz-sulphide veins where ankerite is the main or prevailing mineral. According to the fact, that siderite ore mineralization reaches Triassic members (Lúžnianské layers) near Kumštové sedlo pass, similarly as in Mýto pod Ďumbierom (Majzlan & Chovan, 1997) we suppose that siderite veins were formed still in Upper and Middle Triassic.

Topomineral influence of rock environment was manifested by presence of siderite veins in high-rank metamorphic rocks and ankerite veins in granitoid rocks. That proves also predominance of ankerite over siderite in other Nízke Tatry deposits and presence of Au or Au-Sb mineralization (Magurka, Rišianka, Malé Železné, Nižná Boca, Vyšná Boca - Chopec) that occur in granitoid rocks (Majzlan et al., 1998; Ozdín, 1997). Siderite veins are on the other hand situated only in highly metamorphic rocks of crystalline complex – for instance Jarabá, Mýto pod Ďumbierom – Mlynná dolina valley, Bystrá etc. (Majzlan & Chovan, 1997, Majzlan & Chovan, 1998). At Bruchatý Grúnik carbonates of siderite isomorphous series and carbonates of ankerite-dolomite series occur about in the same ratio. The influence of the rock environment can be explained here so, that the ore mineralization is probably developed on discontinuity zone between Králička type granite and high-rank metamorphic gneisses and migmatites. In contradiction with our results there is the presence of carbonates in the Jasenie-Soviansko deposit where ankerite prevails siderite in high-rank metamorphic rocks (Pouba & Vejnar, 1955).

The highest amount of siderite occurs with quartz-sulphide mineralization, if barite content increases than hematite content increases as well. In ankerite veins there is less siderite and galenite is the main ore mineral.

The occurrences of siderite mineralization and mineral filling of veins is very similar to ore mineralization in the Spišsko-gemerské rudohorie Mts. (for instance Cambel & Jarkovský, ed. 1985). The development of mineralization is in accordance with the present knowledge about mineralisations in Ďumbier part of the Nízke Tatry Mts. (Chovan et al., 1996, Chovan et al., 1998).

Conclusion

Siderite veins occur in intensive mylonite zones almost exclusively in metamorphic rocks of crystalline complex. They are sharply delimited from the surrounding rocks. The prevailing directions of these veins are ENE-WSW. The inclination varies very much, but in studied area the siderite veins incline predominantly to south. The thickness of veins vary, the average thickness is up to 0.5 m. The veins wedge out quickly or gain on thickness, brecciated textures and also noddle and cocarde structures are characteristic.

We have found out the following primary minerals by mineralogical research: aikinite, ankerite, arsenopyrite, barite, benjaminite, bismuthinite, carrollite, friedrichite, galena, gersdorffite, hammarite, hematite, chalcopyrite, cobaltite, quartz, krupkaite, cubanite (?), kutnohorite (?), lindströmite, marcasite, pecoite, pyrite, sphalerite, siderite, schorl (?), tennantite a tetrahedrite. We have described following secondary minerals: aragonite, azurite, covellite, pharmacosiderite, ferisymplesite, goethite, hematite and malachite. In hydrothermally altered rocks at siderite veins vicinity occur: arsenopyrite, biotite, quartz, muscovite, pyrite, rutile and Fe-Ti-bearing oxides.

During investigation of carbonates we have determined that carbonates of siderite series usually predominate in metamorphic rocks on hydrothermal ore veins over the carbonates of isomorphous ankerite-dolomite series. That is opposite in granitoid rocks. The most abundant is siderite with sideroplesite and pistomesite varieties. Dolomite, kutnohorite and calcite were found only in one sample. Aragonite occurs as the secondary mineral in siderite veins.

The mains of sulphide minerals are chalcopyrite and minerals from tetrahedrite and pyrite groups, which are abundant in all of the investigated localities. The subsidiary minerals are arsenopyrite, galena, sphalerite and sulphosalts of aikinite series. Arsenopyrite (max 0,04 wt. % Au) and pyrite (up to 0,19 wt. % Au) are locally gold bearing.

Quartz is the main non-metallic mineral that is the main mineral everywhere. However, in various deposits and occurrences it is present in various forms and it forms at least two generations everywhere. For each ore vein or vein system a specific type of quartz is characteristic that differs by colour, level of crystallisation, light transmissivity, and presence, quantity and form of sulphide, carbonate and barite occurrences in it.

From the mineralogical viewpoint the typical signs of siderite mineralization in the vicinity of Vyšná Boca are: the presence of sulphosalts of aikinite isotype series in all the siderite veins, relatively monotone mineralization and absence of gold and mercury bearing minerals.

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Sapphire from Hajnáčka (Cerová Highlands, southern Slovakia)

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Abstract. Tiny (≤5 mm) blue and pale violet transparent to translucent, locally of the gem-quality sapphire crystals have been found in resedimented psammitic filling of the maar near Hajnáčka village, Slovakia. The maar is associated with Pliocene-Pleistocene alkali basalt volcanism. Homogeneous to slightly zonal sapphire is close to corundum end-member: 99-100 wt.% Al_2O_3, 0-0.9 wt.% Fe_2O_3+FeO, 0-0.7 wt.% TiO_2, 0-0.2 wt.% SiO_2 and 0-0.2 wt.% Cr_2O_3; a = 4.758, c = 12.988 (10^{-10} m), ω = 1.766, ε = 1.758. SEM study of sapphire surface indicates rather magmatic corrosion than alluvial transport. Zircon, monazite-(Ce), spinel, Fe-S phase (pyrrhotite?) and Y-U-Th-Nb-Ta-bearing phase are included in sapphire crystals. Olivine, zircon, garnet, titanite, magnetite, spinel, amphibole (kaersutite), plagioclase and quartz associated with sapphire. Corundum probably crystallized from felsic syenite-like melt, which fractionated from basic-ultrabasic mantle precursor and the crystals were later transported in xenoliths by younger portions of alkali basalt magma up to surface. Finally, sapphire was accumulated in resedimented volcanic and non-volcanic material filling the maar structure.

Key words: corundum, sapphire, alkali basalts, Western Carpathians, Slovakia.

Introduction

The Gemer - Malohont Museum in Rimavská Sobota, Slovakia, in cooperation with the Department of Geology and Paleontology, the Comenius University, Bratislava, has organized a research project in the Hajnáčka maar at Kostná Valley near town of Fiľakovo, approximately 200 km E of Bratislava, southern Slovakia, well-known locality of Pliocene vertebrates. Beside fossils, fine fragments of minerals and rocks have been obtained by washing of fossiliferous beds during systematic paleontological research. Tiny (≤5 mm), notably blue mineral fragments has attracted attention from the obtained material. The mineral has been identified as sapphire, the gem-quality species of corundum. Since size and amount of the mineral is unique in whole the West-Carpathian area, we have subjected the sapphire to detail research. Our article summarizes the first results of the mineralogical research of the locality.

Corundum and sapphire in Neogene volcanic rocks in Slovakia

Slovak occurrences of corundum, especially of sapphire, are genetically associated mainly with Miocene andesite calc-alkali volcanism. Corundum occurs in andesites and its pyroclastic rocks near Sklené Teplice and Dolné Hámre, Štiavnica Mts. (Hvožďara & Činčár 1972), corundum - cordierite hornfels with sillimanite and spinel in andesites near Dobrá Niva, Štiavnica Mts. (Fiala 1954), contact hornfels with sillimanite, andalusite and cordierite in the KR-3 borehole near Kremnica, Kremnica Mts. (Böhmer & Šímová 1976), sekaninaite-bearing xenoliths in andesites from Vechec, Slanské Mts. (Ďuďa et al. 1981), quartz- and Al-metasomatites with topaz, andalusite, etc. from Kapka, Vihorlat Mts. (Derco et al. 1977) and zunyite-quartz metasomatites near Vígľašská Huta, Javorie Mts. (Marková & Štohl 1978). Alluvial corundum occurs in the vicinity of Neogene andesites, e.g. near Boliarov, Kecerovce and Rankovce, Slanské Mts. (Ďuďa et al., 1981).

History of Hajnáčka corundum

The Hajnáčka sapphire occurrence is not a discovery of a new locality but its rediscovery exactly one hundred years after the first description (Szádeczky 1899). Dr. Gyula Szádeczky, a Hungarian geologist, described for the first time a sample of basalt with corundum from "ajnácskoi Csontos-árok", i.e. from Kostolný Jarok near Hajnáčka village, the important paleontological locality known since 19th century. He described the sample found by Dr. Alexei Pápay (Pápay Elek), which belong to the Kolozsvár University collection, Transylvania, recently Cluj in Romania. The grey-blue corundum forms "flat tabular crystal 7 mm in length, outstanding 1.5 - 2 mm out of surrounding yellow-brown weathered crust of basalt, the mineral itself has thin black coating" (Szádeczky 1899). The author mentioned that the described basalt contained also another minerals, probably augite, amphibole, feldspar, pyrite, magnetite and maybe rutile, a blue obsidian and quartz were also present. Szádeczky (1899) emphasized that Hajnáčka corundum was the largest known sample of this mineral in Hungary to date. The whole data were cited later by Rozlozsnik & Emszt (1911) in an article concerning to basalts of Cerová Highlands (Medvesgebirges) and by another authors as well (Melczer 1907, Hintze 1915, Vadász 1940, Mauritz & Vendl 1942; in Koděra et al. 1986). The first, however, not precise chemical analysis of the Hajnáčka corundum showed 89.56 wt.% Al_2O_3, 6.10 wt.% Fe_2O_3 and 5.42 wt.% $SiO_2 + TiO_2$ (Zimányi 1915, in Koděra et al., 1986).

Grey-blue corundum from Hajnáčka (still not denoted as sapphire) was later almost forgotten. There were only few records about it, in mineralogical monographs of Slovakia by Kouřimský (1958) and Herčko (1984), and, of course, in Topographic Mineralogy of Slovakia (Koděra et al., 1986). There were no more records about the corundum occurrence from the Hajnáčka, Kostná Valley. The exact localization of the occurrence was forgotten, in later papers it was referred only as Hajnáčka locality, what could be misunderstood with well-known site on the Hajnáčka castle hill. Only recent extended paleontological research of the Kostná Valley, with several deep pits and washing of large amount of sand has rediscovered not only paleontological material but also sapphire and other minerals from the locality.

Geological settings

The Hajnáčka, Kostná Valley locality is situated 600 m N of the Matrač Hill (410 m a.s.l.), 1 km SE of Hajnáčka village, and around 12 km SE of Fiľakovo town in southern Slovakia (Fig. 1). According to the geomorphological and regional geological division of the subprovince of the Inner Carpathians Mts., the studied locality belongs to the unit of Cerová Highlands. The site is an important European paleontological locality of Upper Pliocene age located in an erosional valley, 400 m in length, 30 m in width and up to 20 m deep, with E-W orientation. In 1994, the site with surrounding area were pronounced for the Kostná Valley Natural Reservation with area of 4.92 hectares.

The site is part of the Cerová Basalt Formation (Vass & Kraus 1985), which contains mainly alkali basalts and volcanic clasts. K-Ar radiometric dating of the basalts revealed Pliocene - Pleistocene ages between 1 - 5 Ma (Orlický et al. 1996, Vass et al. in press).

The Hajnáčka, Kostná Valley occurrence is located in a volcanic maar structure (Konečný & Lexa in Vass et al. 1992, Vass et al. in press). The maar has elliptic shape about 400-500 m in diameter, partly covered by Pleistocene alluvial sediments. Erosion relicts of volcanic ring on the maar margin are formed by basaltic lapilli tuff deposited during freatomagmatic eruptions. Central part of the maar is built by redeposited sedimentary filling, which is composed of the Tachty sads to sandstones of the Fiľakovo Formation (Eggenburgian) in the basal part. In overlaying beds, there are layers of lapilli tuffs and tuffites with fragments of basalts and burnt sandstones enveloped by limonite crusts, less frequently occur redeposited palagonite tuffs and breccias. Locally, there are relicts of laminated bituminous beds, remains of original lacustrine maar filling, which is partly covered by Quaternary loamy and argillaceous deposits (Fig. 2).

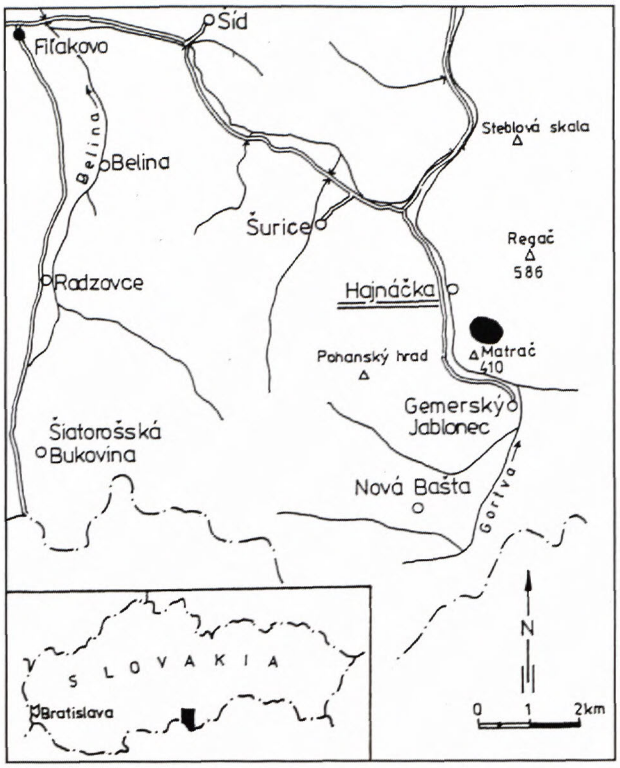
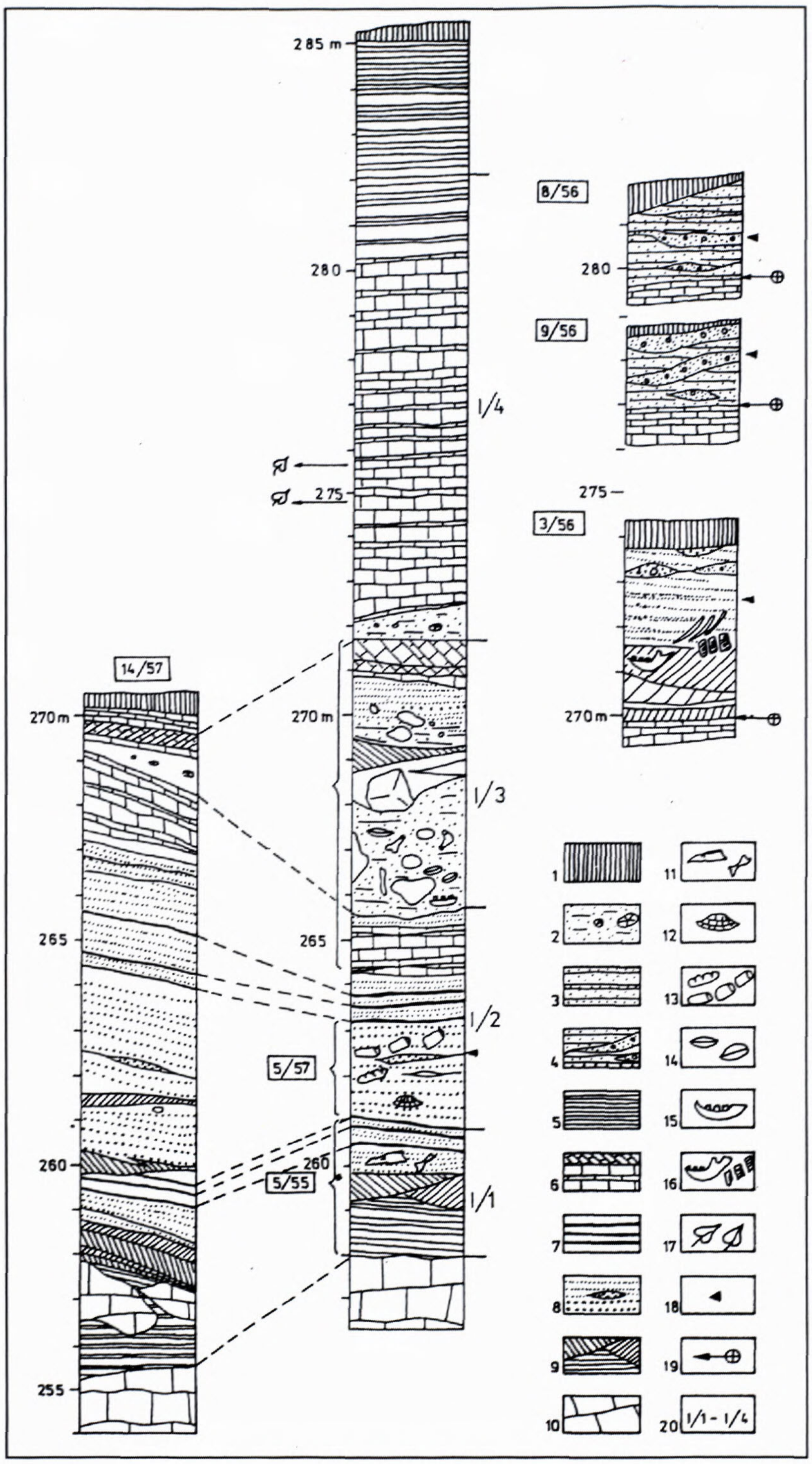


Fig. 1. Location of the sapphire occurrence, the Hajnáčka maar, Kostná Valley.

Results of remanent magnetism analysis from the ring tuff of maar corresponds to an event with normal Earth magnetic polarity (3n) in a lower part of the C2An chron, what indicates the age of maar formation between 3.3 to 3.55 Ma ago (Vass et al. in press). An accumulation of fragments of mammalian skeletons is younger, it was created during redeposition of original and input of new clastic sediments, when the original sedimentary maar filling has been almost entirely eroded away. Fossil findings were found in more or less preserved beds with completely preserved stratigraphic beds without hiatus. The mammalian bone remnants from the Hajnáčka, Kostná Valley was dated to biozone MN 16a, late Vilafranch (topmost Pliocene), on the basis of index fossils, such as *Mimomys (Cseria) stehlini, Mimomys (Mimomys) hajnackensis, Tapirus arvernensis, Dicerorhinus jeanvireti* and *Anancus arvernensis*, what belongs to the middle part of the C2An chron and time interval between 2.8 to 3.3 Ma ago (Lindsay et al. 1997, Vass et al. in press).

Fig. 2. The geological profiles of the sapphire occurrence in Vilafranchian beds, the Hajnáčka maar, Kostná Valley. The profile in the middle was composed from other partial profiles from this territory (modified after Fejfar et al. 1990): (1) the Quaternary colluvial deposits with the Holocene soils; (2) fine tuffaceous sands with lapilli and limonite concretions; (3) stratified sandy tuffites with fragments of the basalts and bones; (4) fine tuffaceous sands with intercalations or lenses of the coarser sandy tuffites; (5) fine banded tuffites; (6) sheeting and current bedding of the sandy tuffites;(7) fine sands with white laminated tuffites; (8) fine tuffaceous sands with limonite intercalations and fossiliferous tuffaceous lenses; (9) fine cross bedding sands with fossils in the limonite concretions; (10) sandstones from the Upper Oligocene (Chattian); (11) remains of the tapirs; (12) Chelydra remains; (13) remains of the mastodonts; (14) Anodonta shells; (15) remains of the Pliocrocuta perrieri; (16) remains of the Anancus arvernensis; (17) remains of the plants; (18) remains of the micromammals; (19) shear zones; (20) levels of the findings.



Experimental methods

Sapphire and other accessory minerals were obtained by washing of ca. 1,000 kg of resedimented psammitic - sediments from fossils-bearing layers of the Hajnáčka, Kostná Valley.

The crystal morphology, internal zonality and inclusions in sapphire was studied by a JEOL JSM-840 scanning electron microscope, at Geological Survey of Slovak Republic, Bratislava. Secondary (SEI) and back-scattered (BSE) electron modes were used. The accelerating voltage was 25 kV, beam current was 1 nA (SEI) and 30 nA (BSE).

Electron-microprobe analysis was done on a JEOL-733 Superprobe instrument equipped with KEVEX energy dispersive system (EDS), at Geological Survey of Slovak Republic, Bratislava. Operating conditions were 15 kV acceerating voltage, 1.2 nA beam current and 130 s count time. Synthetic standards: SiO_2 (Si Kα), TiO_2 (Ti Kα), Al_2O_3 (Al Kα), Fe_2O_3 (Fe Kα), and chromite (Cr Kα), were used. The detected concentrations of elements were recalculated by the XPP correction.

The structural identification of sapphire was done by the powder Debye - Scherrer X-ray diffraction method using a Philips PW 1710 diffractometer, at Geological Institute, Slovak Academy of Sciences, Bratislava. Pulverized sample was mixed up with α-SiO_2 internal standard. Cu-anticathode ($\lambda_{\alpha 1}$ = 1.54060 x 10^{-10}m), 20 mA current, 35 kV voltage, interval of 2 Θ equals to 10-80° and step speed of 0.3° 2Θ/min was used for measurement. Presence of plagioclase and titanite was also determined by the powder X-ray diffraction analysis.

Index of refraction (ω, ε) was done on a two-circle Freiberger Präzisionmechanik goniometer, at Czech Geological Institute, Prague. The method of minimal deviation in sodium light was used. The sapphire crystal was embeded into epofix, and a prism with angle 48°27' was shaped from it, such a way, that the *c* crystallographic axis lays in a plane dividing the prism's angle into two halfs.

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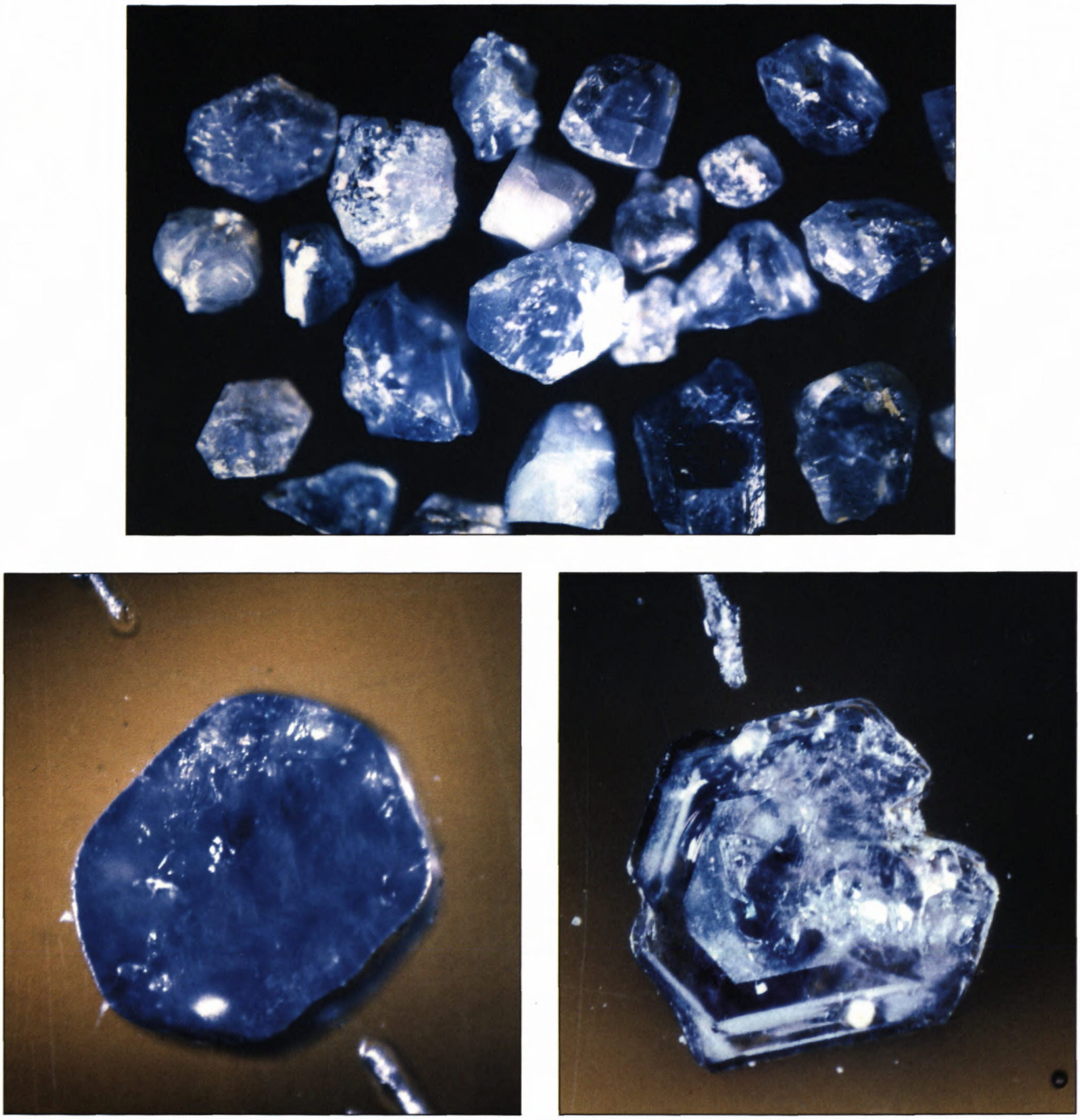

Fig. 3A-C. Sapphire from Hajnáčka, southern Slovakia (L. Osvald photo).

Results

Physical properties

Sapphire occurs as well shaped prismatic crystals with {1010} and {1011} faces, locally also with {1011} dipyramidal faces. In most cases, sapphire crystals occur as fragments (1-5 mm in size), locally partly rounded. The largest crystal has weight about 0.1 g (0.5-0.6 metric carats). Sapphire shows mostly light to deep blue color, in some cases grey blue to pale violet, the mineral is perfectly transparent to translucent with vitreous to dull luster (Fig. 3A-C). Some crystals have gentle dichroism. Locally, the sapphire reveals visible growth zones (Fig. 3C).

The refractive index of Hajnáčka sapphire is ω = 1.7664(5), ε = 1.7581(5), birefrigence B = 0.0083, the values are well corresponding with corundum data (ω = 1.765-1.779; ε = 1.757-1770; B = 0.008-0.009; Bernard & Rost 1992; Ďuďa & Rejl 1998).

Crystal morphology

Details of sapphire crystal morphology show various roundness degree of originally flat and smooth crystal faces (Fig. 4A-D). Figures 4A-B show alteration of primary sapphire surface along lines parallel to the {0001} face as a plane of corundum jointing together with rounding of surface elevations. Fig. 4C shows another sapphire with system of straight ribbed projections and neighboring holes with slight trend orientation. Finally, Fig. 4D shows surface of finely sculptured sapphire with straight thin scratches and holes of prismatic shape. Details of sapphire crystal morphology reminds mainly signs of magmatic corrosion, however, scratches on the crystal surface indicates also mechanical transport and the elongated holes are probably negatives after inclusions of unknown minerals (cf. Coenraads et al. 1990, 1995, Malíková 1996).

Structural parameters

X-ray diffraction pattern, as well as calculated structural parameters based on four sapphire crystals from Hajnáčka, proved sapphire's identity with a tabelated corundum, calculated structural parameters of sapphire: a = 4.758(4) and c = 12.988(7) [10^{-10}m] are almost identical with JCPDS values (α-Al_2O_3, JCPDS #10-173). This result indicates a high purity of the Hajnáčka sapphire which approaches theoretical Al_2O_3, what has been proved also by electron microprobe analyses.

Internal zonation and chemical composition

The study of polished sections of the Hajnáčka sapphire by backscattered electrons image (BEI) didn't show any chemical zonality of the mineral, crystals with distinctive optical zonation (Fig. 3B) are also chemically homogeneous.

Electron microprobe analysis, done on 20 points of 7 crystals, shows a high purity of the mineral (99-100 wt.% Al_2O_3, Table 1). Isomorphic admixtures comprise 0.0-0.9 wt.% Fe_2O_3 (however it is probably a mixture of both Fe^{+3} and Fe^{2+}), 0.0-0.7 wt.% TiO_2 and 0.0-0.2 wt.% SiO_2.

Table 1 Compositions of sapphire from Hajnáčka (wt %)

	1CORE	1MID	2CORE	2RIM	3CORE	3RIM
SiO_2	0.12	0.21	0.15	0.22	0.24	0.21
TiO_2	0.27	0.65	0.00	0.00	0.00	0.00
Al_2O_3	98.98	98.34	99.19	98.56	99.57	99.29
Cr_2O_3	0.00	0.00	0.00	0.00	0.17	0.18
Fe_2O_3	0.50	0.49	0.78	0.89	0.00	0.37
Total	99.87	99.69	100.12	99.67	99.98	100.05
Formulae based on 6 oxygen atoms						
Si	0.004	0.007	0.005	0.008	0.008	0.007
Ti	0.007	0.017	0.000	0.000	0.000	0.000
Al	3.977	3.960	3.980	3.975	3.985	3.979
Cr	0.000	0.000	0.000	0.000	0.005	0.005
Fe	0.013	0.013	0.020	0.023	0.000	0.010
Total	4.001	3.997	4.005	4.006	3.997	4.001

Content of Cr_2O_3 is usually under detection limit of the microprobe (<0.2 wt.% Cr_2O_3). The concentrations of the admixtures are almost identical in the centre and the rim of sapphire crystals, small variations are not systematic.

Mineral inclusions in sapphire

Zircon occurs as idiomorphic to xenomorphic inclusions, 50-200 µm in size.

Monazite-(Ce) forms 100-200 µm large euhedral inclusions. Locally, it occurs in the same crystals as inclusions of zircon. Microprobe analyses reveal compositional zonality of monazite-(Ce) with edges slightly enriched in Th (2.6 wt.% ThO_2).

Spinel was found only in one case, as ~500 µm irregular inclusion near the rim of the sapphire crystal. The mineral reveals compositional zonality in Cr and Fe (2.8-8.8 wt.% Cr_2O_3 and 14-16 wt.% FeO+Fe_2O_3).

Fe-S-bearing phase, most probably *pyrrothite(?)* forms inclusions of 200-300 µm large tabular crystals together with zircon and monazite-(Ce) inclusions.

Y-U-Th-Nb-Ta-bearing phase, probably *euxenite-(Y)?* or *mineral of pyrochlore group(?)*, was observed only in one case, as ~250 µm irregular inclusion near the edge of sapphire.

Associated minerals

Zircon occurs as red transparent short-prismatic-dipyramidal crystals (variety hyacinth). *Olivine*, probably *forsterite*, forms light blue fragments and prismatic tabular crystals. *Garnet* (*pyrop* or *almandine*) forms dark blue, partly altered crystals, locally containing inclusions of *ilmenite* and *allanite*. *Titanite* occurs as transparent to translucent honey-like colored fragments, locally as intergrown with *magnetite*. *Plagioclase* forms relatively large fragments (≤8 mm) of prismatic and tabular crystals of white color and typical striated crystal face. Greyish-black *spinel* of typical dipyramidal shape and black *amphibole*, probably *kaersutite* are less frequent Relatively abundant colorless *quartz* forms irregular fragments or dipyramidal transparent crystals. The size of above mentioned minerals in the maar filling vary from 1 to 8 mm, 3-4 mm in average.

Discussion

World alluvial and elluvial occurrences of gem-quality sapphire are associated mainly with alkali basalt rocks, namely with explosive continental alkaline volcanism with predominance of basanite, often with abundant ultramafic mantle xenoliths, e.g. East Australia, Thailand, Cambodia, Vietnam, south China, Colombia, Nigeria and Czech Republic (Coenraads et al. 1990, 1995, Sutherland et al. 1998, Kotrlý et al. 1997). Alluvial and elluvial sapphire-bearing deposits connected with the alkali-basalt volcanism contain a characteristic heavy-mineral assemblage, including zircon, spinel, ilmenite, occasionally olivine, clinopyroxene, garnet, magnetite and locally also diamond (Australia, Coenraads 1990). Sapphire crystals from alluvial and elluvial deposits have, beside signs of mechanical transport, also features of magmatic corrosion (Coenraads et al. 1990, 1995, Malíková 1996, Kotrlý et al. 1997). Inclusions of zircon, magnetite, spinel

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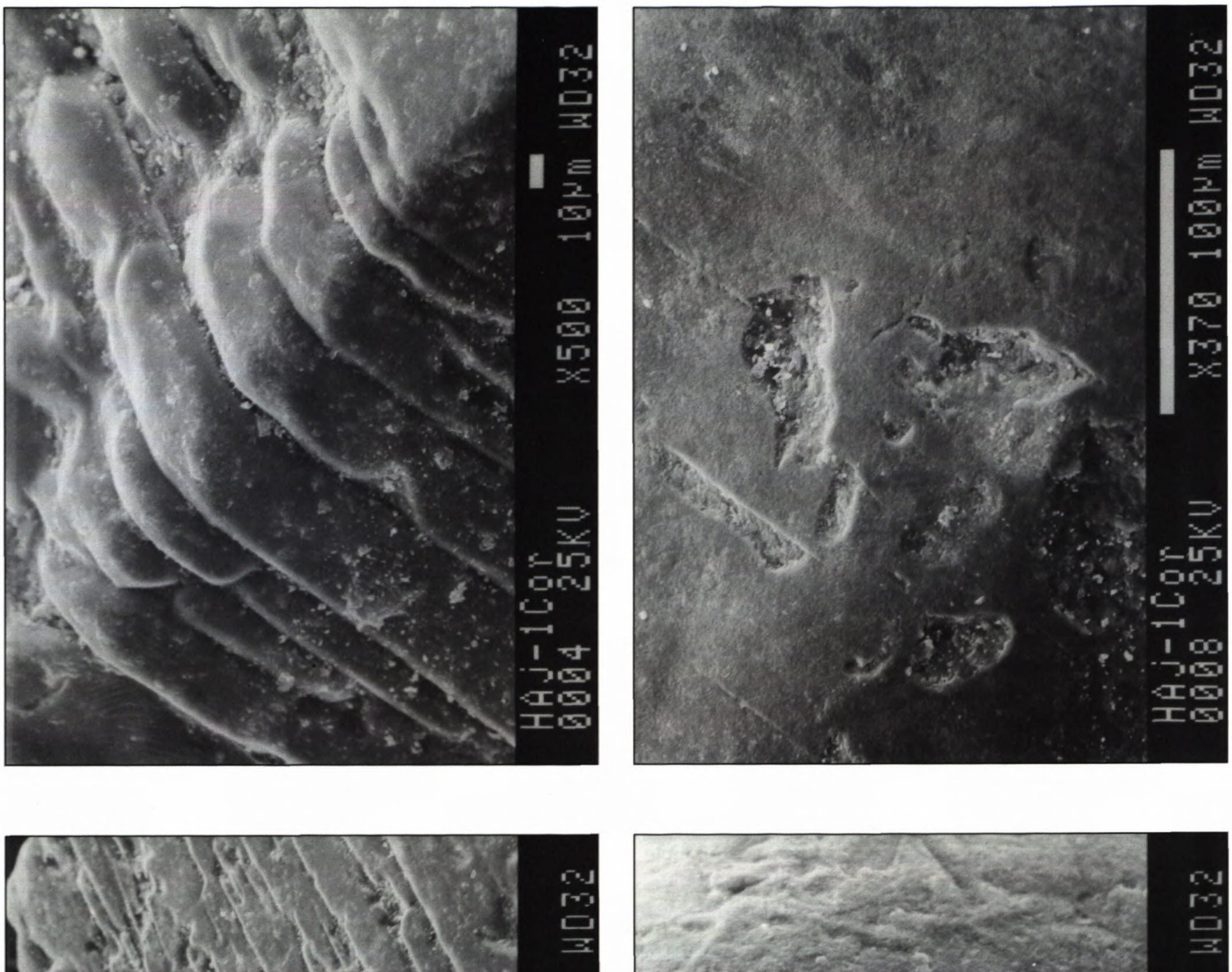

Fig. 4A-D. Morphology of sapphire from Hajnáčka, southern Slovakia (SEI, K. Horák photo).

(also Co-rich), hercynite (often Zn-rich), ferrocolumbite, niobian rutile, thorite, U-Ti-rich pyrochlore, apatite, REE-phosphate, pyrrhotite, almandine, pyrope, alkali-feldspar and plagioclase are present in sapphire (Sutherland et al. 1998, Guo et al. 1994). Surprisingly, these incorporated minerals contain elements incompatible in basic magma such as Zr, Nb, Ta, U, Th, REE`s and elements of alkali metals. Sapphire often contain fluid inclusions, often CO_2-rich (Coenraads et al. 1990, 1995, Guo et al. 1994, Malíková 1996, Sutherland et al. 1998). A detailed study of the fluid inclusions, Fe-Ti-oxides and feldspars indicates the temperature of corundum formation in the range of 685 to 900 °C (Sutherland et al. 1998). Zircon inclusions in sapphire from Australia and Thailand, dated by U-Pb method, yield ages similar to alkali-basalt extrusions (Coenraads et al. 1990, 1995).

The above mentioned results indicate a magmatic origin of sapphire and associated minerals from a felsic melt enriched in incompatible elements. Some authors - supposed phonolite (or nepheline syenite) composition of this melt originated by fractionation of mantle-derived - basalt rich in kaersutite, clinopyroxene, olivine, Fe-Ti spinel, etc. (IRVING & Price 1981, Irving 1986). The latest petrological model assumes low-degree partial melting of amphibole-bearing mantle pyroxenite and its subsequent fractionation which produced a fluid-enriched felsic magma (Sutherland et al. 1998). Sapphire and other phases solidified from the felsic melt in lower crust and later they have been transported to the surface as xenocrysts or xenoliths in alkali-basalt magma (e.g. Coenraads et al. 1995).

According to another model, the origin of sapphire and diamond in Victoria, Australia is associated with - Paleozoic subduction and the minerals remained in upper mantle until their uplift by Tertiary alkali-basalt magma (Birch 1998). Some authors prefer processes of magma mixing in lower crust with contemporaneous crystallization of sapphire and other minerals (Guo et al. 1994). Others relate the origin of some alluvial sapphires with metamorphic processes in the crust (e.g. Garland 1998).

Mineral inclusions containing elements incompatible in basalts (monazite-(Ce), zircon and Y-Th-U-Nb-Ta-bearing phase) and character of sapphire morphology with signs of magmatic corrosion indicate that the Hajnáčka sapphire was originated in felsic melt and uplifted to the surface as xenocrysts which were not in equilibrium with surrounding alkali basalt magma. This assumption supports also nepheline-olivine normative, not corundum normative compositions of the alkali basalts from Hajnáčka area (Konečný & Lexa in Vass et al. 1992) showing that the alkali basalts are not in - equilibrium with corundum and therefore they don`t represent the parental magma for sapphire.

As a possible parental rock of the Hajnáčka sapphire, we suggest felsic syenite-like xenoliths. Although these xenoliths are unknown from the Hajnáčka maar to date, syenite and anorthosite xenoliths are present at the Pinciná maar belonging to older, Pliocene the Podrečany Basalt Formation, situated 23 km NW of Hajnáčka. Moreover, the Pinciná syenite xenoliths contain corundum and other accessory minerals similar to Hajnáčka, such as zircon, spinel, amphibole, apatite, titanite, monazite, xenotime, Y-U-Th-Nb-bearing oxides, Y-silicates and REE-minerals (Huraiová et al. 1996, Hurai et al. 1998). Consequently, the analogous syenites represent - probably the host rocks of the Hajnáčka sapphire and some other associated minerals.

Presented geological and mineralogical data indicate that the sapphire from Hajnáčka, Kostná Valley is spatially related to the Cerová alkali basalt Formation of Pliocene to Pleistocene age. We assume that corundum from redeposited sedimentary filling of the Hajnáčka maar is most probably related by the syenite-like magma. This felsic syenitic melt could be generated by fractionation of basic magma originated by partial melting of upper mantle rocks. Subsequently, syenitic magma solidified probably in the lower crust level and later it was uplifted to the surface as xenoliths. Finally, sapphire and other minerals accumulated in redeposited sediments that filled the maar structure. It is not clear so far, whether sapphire come from nearby basalt lava flows or from the maar itself.

Conclusions

Blue and pale violet sapphire, locally of gem-quality, was obtained from Upper Pliocene resedimented psammitic maar filling at Hajnáčka, Kostná Valley in southern Slovakia, well-known paleontological occurrence for findings of mammalian fossils. Sapphire was firstly described by Szádeczky (1899) one hundred years ago and was in fact rediscovered at present only. Physical and structural parameters of the sapphire are in good agreement with published data. Sapphire is relatively very pure with low contents of Fe, Ti and Si.

Crystal surface, mineral inclusions and spatial relationship with alkali basalts indicate sapphire crystallization probably from a fractionated felsic syenite-like melt. The melt was generated by fractionation of basic magma on the mantle/crust boundary or in the lower crust. In later stage sapphire was transported up to the surface as xenocrysts or in syenitic xenoliths by a new portion of alkali basaltic melt. Accessory minerals including sapphire separated from host rocks and sedimented in the maar filling. It remains questionable, whether sapphire was transported in some of nearby alkali basalt lava flows or in volcanoclastics building up the Hajnáčka maar structure.

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Pliocene deposits of Rišňovce Depression - Volkovce Formation

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Abstract. Sandy deposits of the Pliocene Volkov Formation in the Rišňovce Depression were studied at the localities of Dolné Otrokovice, Dolné Trhovište, Tepličky and Piesočnica near Behynce (Fig. 1). They probably represent sandy deposits of rivers entering a fresh-water lake. Palaeoflow direction, detected from vector measurements of cross lamination, is from NW to SE. Heavy mineral analysis suggests two possible source areas. Rutile, zircone, ilmenite and garnet suggest the crystalline source area, which according to the palaeoflow direction (from NW to SE) is located in the Považský Inovec Mts. The occurrence of β quartz suggests a source area with volcanic material which might have been delivered by tributaries from the Ruskovce Formation found in the Bánovce Depression.

Key words: Pliocene, Danube Basin, Rišňovce Depression, sedimentology, fluvial deposits, delta

Introduction

The sedimentary fill of the Rišňovce Depression consists of Neogene deposits transgressively and discordantly overlying pre-Neogene rocks. Regional geologic investigation supported by stratigraphic study of borehole profiles (Maglay et al., 1997) is being conducted in the study area.

The Pliocene Volkovce Formation and the Pontian deposits crop out at several localities in the study area. They are composed of variegated calcareous clay containing a variable sand admixture and variegated sand interlayers. Older authors refered to them as the variegated series. They were correlated with the G-H Zone of the Panonian, later with the Pontian and finally they were assigned to the Pliocene (Priechodská and Harčár, 1998).

Deposition prevailingly occurred in the river-dominated environment. We did petrographic, sedimentologic and grain-size analysis of the deposits.

Geologic background of the study area

According to the regional-geomorphologic division of the Slovakia the study area is a part of the Danube lowland. It occurs in the sub - units present in the Nitra Hills and the Nitra flood plain (Mazúr and Lukniš 1978). Following the regional geologic division of Slovakia the area is a part of the Rišňovce Depression belonging to the Danube Basin (Vass et al. 1988).

The Early to Middle Miocene represents an extensional synrift stage of the Danube Basin development (Kováč and Baráth 1995; Kováč et al., 1997). During the Middle Miocene the subsidence of the Rišňovce Depression was controlled by normal NE-SW trending faults. The sedimentary fill is mostly composed of sandy-clayey marine deposits commonly containing a tuff admixture. In the northern marginal area deltaic and brackish deposits occur (Vass et al., 1990). A sea-level fall connected with the erosion of older deposits is documented in the area of the Alpine-Carpathian junction (Hudáčková and Kováč 1993). Marine transgression during the Late Sarmatian resulted in formation of depocenters in the N and NW parts of the Danube Basin. The Rišňovce Depression, with prevailing deltaic deposition, represents one of these depocenters. The brackish development of the Sarmatian sea was caused by opening of the Badenian seaways to the Mediterranean area. The Panonian and Pontian subsidence, representing a postrift stage of the Danube Basin development, was still controlled by normal faults of the extensional regime along the northern margin of the basin. The deposition during the Late Miocene was influenced by a deltaic environment developing into a limnic estuary (Jiříček 1990).

The sedimentary fill of the Rišňovce Depression consists of the Badenian, Sarmatian, Panonian, Pontian and Dakian (Tab. 1), eventually also of Romanian deposits (Buday et al., 1962, Vass et al., 1990).

Badenian: Deposition in the Rišňovce Depression commenced by the Middle Badenian Špačina Formation (Jiříček 1985) transgressively and discordantly overlying the pre-Neogene deposits composed of the Mesozoic rocks of the Tatricum and Fatricum (Fusán et al. 1987). Špačina Formation consists of clayey-sand, sand and minor gravel deposits (Biela 1978).

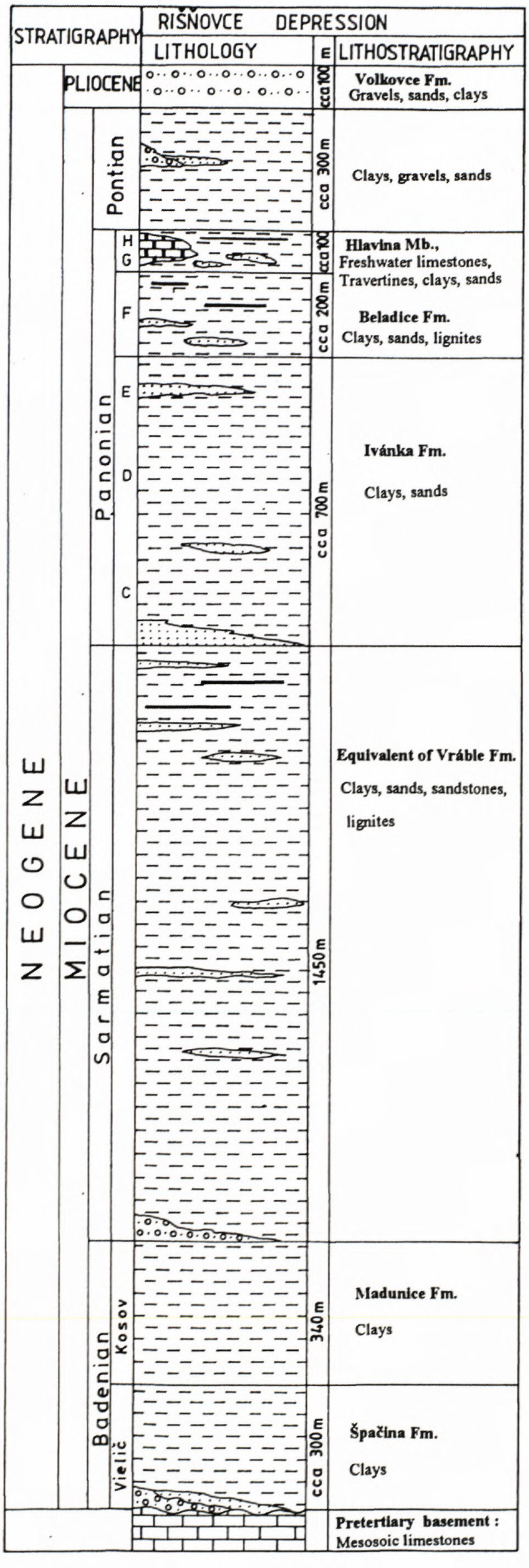
The Late Badenian is represented by the Madunice Formation (Jiříček 1978), consisting of grey clay and calcareous clay with sand layers.

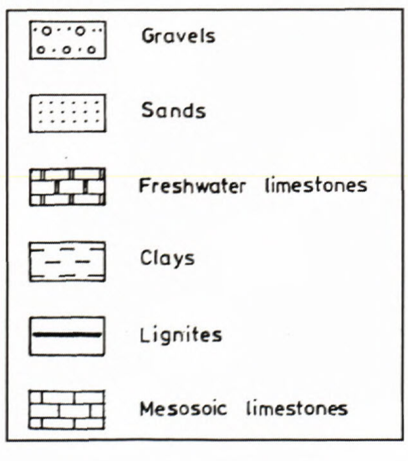
Sarmatian: The Sarmatian deposits represent the equivalent of the Vráble Formation (Harčár et al., 1988) and they can be divided into conglomerate-sandy, sandy-clayey and clayey development.

Panonian - Pontian: During the Panonian and Pontian deposition continued in a fresh-water environment. The Panonian (Zone A-E, Papp 1951) sediments are the analog of the Ivanka Formation (Harčár et al. 1988) and they are mainly known from the western part of the study area. They are mainly of a sandy-clayey character. Zone A, with *Miliamina subvelatina* and *Trochamina kobleri,* is several meters thick and is composed of clay with a sand admixture. Zone B, with *Hungarocypris auriculata - Amplocypris globosa,* is represented by grey calcareous pelites. Zone C is biostratigraphically documented in the Ripňany - 1 borehole (Gaža 1968) and consists of grey sandy clay with layers of calcareous sand. Besides the clay and sand, the formation also contains layers of dark grey and black clay. Microfaunally it is characterized by the ostracod genus *Pontionella acuminata* and *Cyprideis ventricea.* The Panonian zones C - D - E are documented by an abundant fauna of limnocardium - *Limnocardium conjugens* (PARTSCH), *Limnocardium brunense* (HOERNESS). Ostracoda are represented by *Pontionella acuminata* and *Cyprideis Ventricae.*

The Beladice Formation consists of deposits assigned to the Panonian Zone F (Papp 1951). They were assigned to the Pontian in the past. They are the analog of the beds commonly called coal series and they are characteristic by clayey-sandy layers containing lignite lenses. The Zone F is stratigraphically documented by boreholes Topoľčany 1 - 6 drilled east of the study area (Lunga 1965). Zone F is biostratigraphically documented by the occurrence of the macrofauna tests with preserved forms of *Limnocardium conjugens* (PARTSCH) and *Congeria czejiki.* Also, beds containing plant remnants *Glyptostrobus europaeus* (BGT) Hoer and fragments of oogonia characea. *Melanopsis bauei* (FER.) and fragments of *Bithynia tentaculata* (L.), *Congeria neumayrii* (ANDR.), *Planorbis sp.* were identified from the basal part of the Zone F. The plant remnants are represented by oogonia fragments of *Chara meriani* (UNGER).

The Hlavina Member (FORDINÁL and NAGY 1997) is assigned to the Panonian H Zone (PAPP 1951). The deposits are characterized by the occurrence of freshwater and limnic limestone associated with gravel, sand and clay deposits.





Tab. 1. Lithostratigraphic column of the neogene deposits of the Rišňovce Depression. (compiled by Fordinál 1997).

<table>
<tr><th rowspan="2">Former names of lithostratigraphic units</th><th colspan="8">Dividing of the Pannonian into zones. The zones in the stages after diferent authors.</th><th colspan="2">Lithostratigraphic units of the Danube basin</th></tr>
<tr><th colspan="2">Papp, 1951</th><th colspan="2">Jiříček – Švagrovský, 1975</th><th colspan="2">Papp, 1986</th><th colspan="2">Rögl et al., 1993</th><th>Priechodská et al., 1988</th><th>Fordinál – Nagy, 1997</th></tr>
<tr><td>„variegated„ series</td><td rowspan="8">Pannonian</td><td>H</td><td rowspan="2">Pliocene</td><td rowspan="2">Dacian</td><td rowspan="8">Miocene</td><td rowspan="3">Pontian</td><td rowspan="8">Miocene</td><td rowspan="8">Pannonian</td><td rowspan="2">Volkovce Fm.</td><td>Hlavina Mb.</td></tr>
<tr><td>„blue„ series</td><td>G</td><td></td></tr>
<tr><td>„coal„ series</td><td>F</td><td rowspan="6">Miocene</td><td>Pontian</td><td rowspan="2">Beladice Fm.</td><td rowspan="2">Beladice Fm.</td></tr>
<tr><td rowspan="5"></td><td>E</td><td rowspan="5">Pannonian</td><td rowspan="5">Pannonian</td></tr>
<tr><td>D</td><td rowspan="4">Ivánka Fm.</td><td rowspan="4">Ivánka Fm.</td></tr>
<tr><td>C</td></tr>
<tr><td>B</td></tr>
<tr><td>A</td></tr>
</table>

Tab. 2. Opinions of the different authors on subsumption zones into stages, an overwiev. (compiled by Fordinál & Nagy 1997).

Pontian: Deposits of commonly called clay series of the Zone F or Beladice Formation were assigned to the Pontian in the past (Priechodská & Harčár 1988). Because the deposits are assigned to the Panonian, sensu Fordinál and Nagy (1997), the up to now nameless freshwater deposits in the basin overlying the deposits of Hlavina Member, are assigned to the Pontian.

Dacian: The Pliocene is only represented by the Volkovce Formation in the study area. The deposits of the formation are mostly covered by the Quaternary sediments (Priechodská and Harčár 1988) and crop out only in scattered sites. They occur together with the Pontian deposits mainly in the western part of the area.

The deposits were only identified as the variegated series by the older authors and they were correlated to the Panonian Zones G - H, later to the Pontian and recently they were assigned to the Pliocene (Dacian). The deposition occurred in freshwater, either in a lacustrine or a fluvial environment. The deposits of the Volkovce Formation are represented by variegated calcareous clay with a variable admixture of sand grains. Layers of grey calcareous sand as much as 10 m thick and locally also layers of sandy gravel occur in the clay. Immediately beneath the Quaternary deposits grey fine- and coarse-grained calcareous, yellowish-gray and brownish-yellow sand with layers of weakly consolidated sand occur. This sand contains irregular layers of fine-grained gravel. According to Elečko (Pristaš et al., 1998) the deposits originated in alluvial fans and deltas.

Suggestions concerning the stratigraphic division of the Panonian or Pontian are summarized in Table 2. The lithostratigraphic division of the Panonian - Pliocene deposits, considering the latest suggestions (Fordinál and Nagy 1997) is following:

1. Ivánka Formation - Panonian (Zones A - E)
2. Beladice Formation - Panonian (Zone F)
3. marginal Hlaviná Member - Panonian (Zone H) and its equivalent in the basin
4. Volkovce Formation - Dacian

Methods

Sediment analyses in the study area are based on field processing represented by a detail sedimentologic documentation of the outcrops and samples. The samples were later processed in laboratories.

Methods of grain-size analysis, hydraulic methods for measurement of the smallest grain size fraction, heavy mineral analyses aided by X - ray and DT analysis were applied. The X - ray analyses from five samples taken from the clay rip-up clasts were done at the Geologic Survey of Slovak Republic. The RTG diffractograph DRON - 3 CuK alpha radiation, filter Ni associated with the program for powder analysis by the ZDS system were used for the RTG analysis of clay minerals.

The samples with a grain-size fraction below 0.002 mm were processed in the laboratory. The samples were diluted by distilled water and after addition of 15% HCL solution they were scrubbed 2 - 3 minutes by ultrasound. The mixture, homogenized by ultrasound, was dropped on a mount and thin sections were made. The samples were saturated by ethylenglycol.

Heavy minerals from the grain-size fraction in the 0.25 - 0.1 mm and the 0.1 - 0.05 mm ranges were separated in bromoform (gauge mass 2.88 kgm^{-3}). The separated heavy fraction was divided by a magnet in to a magnetic fraction and further, by an electromagnet, into a dia-magnetic fraction and para-magnetic fraction.

Lithology

The deposits of Volkovce Formation are well exposed near of Dolné Otrokovice, Dolné Trhovište, Tepličky and Piesočnica all near Behynce in the area of the Nitra Hills (Fig. 1).

The section of Dolné Otrokovice DO/1, DO/2, is shown in figures 2 and 3. It is exposed in a sand pit that lies 500 m NW of the village. The outcrop mainly consists of coarse-grained sand (the sand content in the sample is 69.93%), fine-grained sand and silt. The coarse-

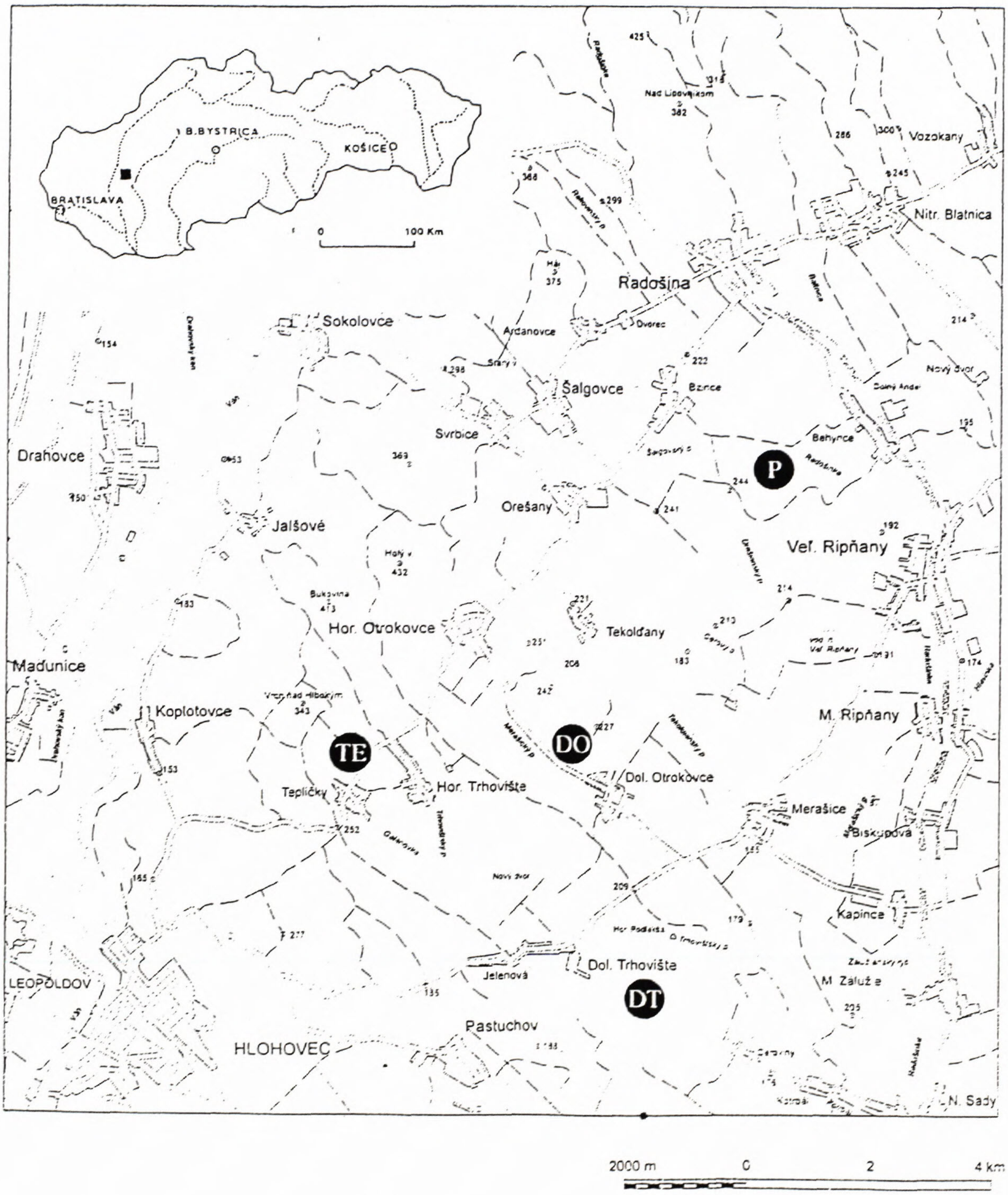


Fig. 1: Schematic map and location of the studied localities of Dolné Otrokovce (Do), Dolné Trhovište (DT), Tepličky (TE), Piesočnica near Behynce (P).

grained sand commonly contains an admixture of fine-grained gravel (11.96%) with clasts up to 1 cm. The admixture of fine-grained sand is 12.16% and silt admixture is 12.73%. The sand is yellow, ocherous-yellowish and brown. Sand grains are medium sorted.

The section of Dolné Trhovište DT/1 is shown on figure 4. It is situated on slope Dingov in the middle of the field about 1 km E of the village of Dolné Trhovište. It consists mainly of fine-grained sand (64.01 %). The medium-grained sand is present to 10.19%, the coarse-grained sand comprises 4.57 % and fine-grained gravel makes up 0.07 %. The mean silt content is 17.2 %. The sand is medium sorted and is grayish-white, white, dark-yellowish and rusty-brown.

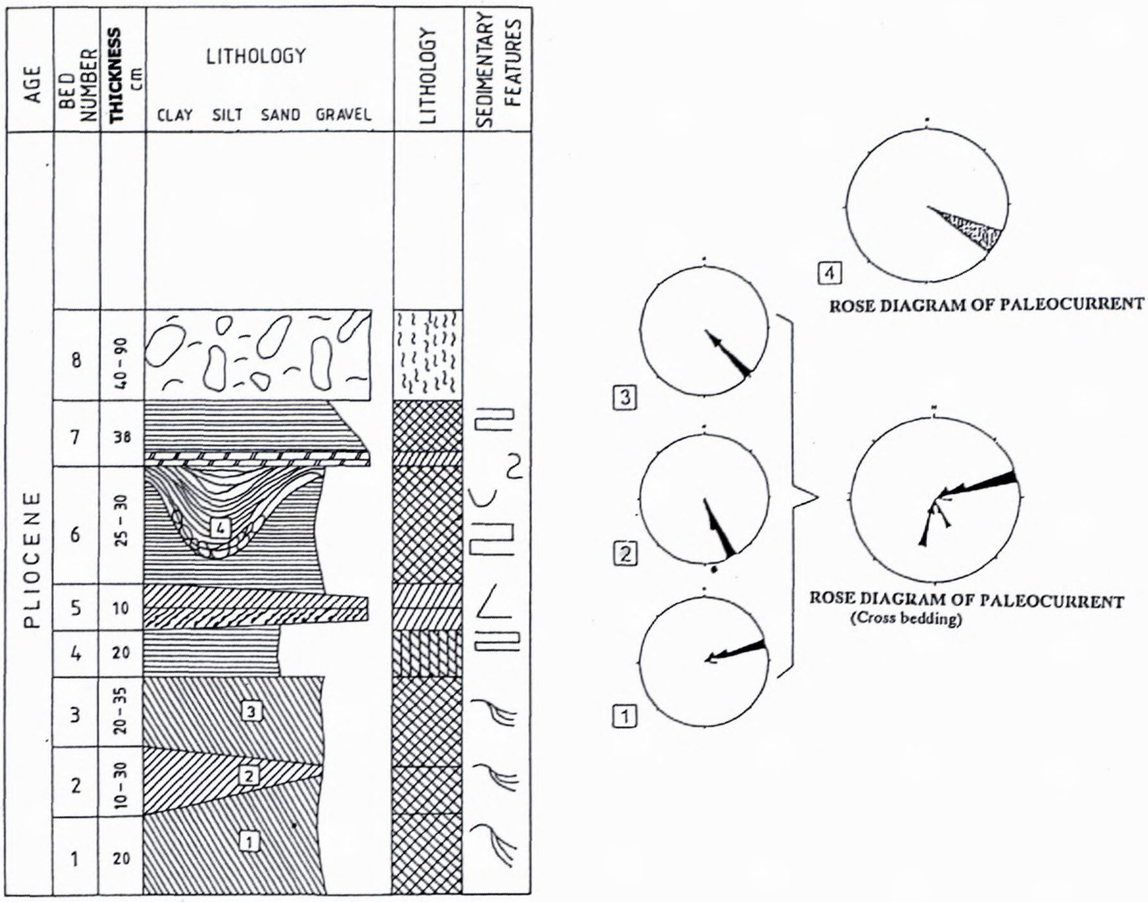
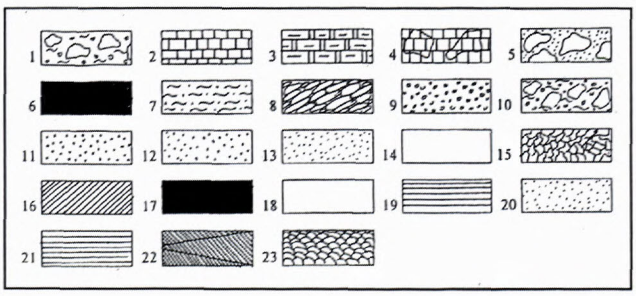


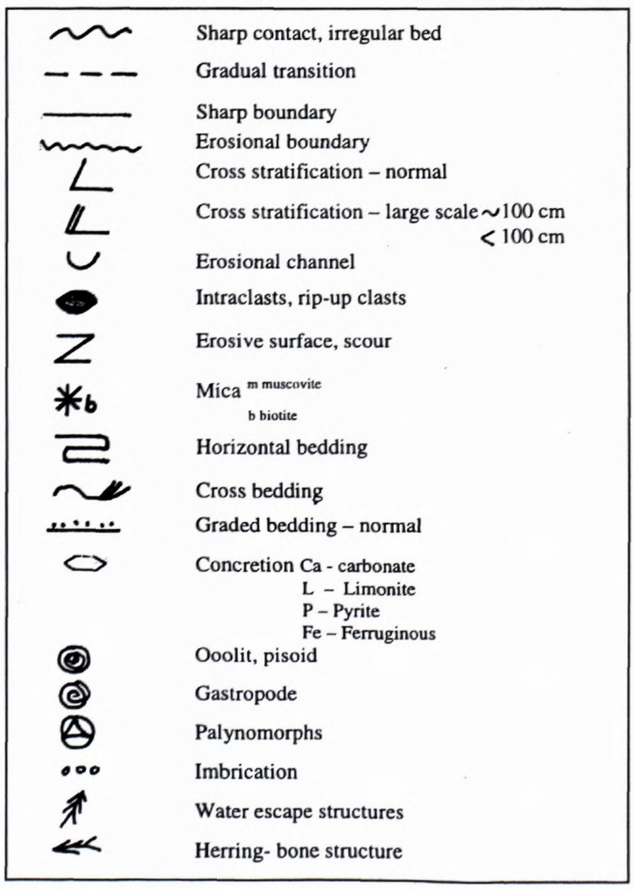
Fig. 2. Section of Dolné Otrokovce DO/1 (n = 30)



Legend to Fig. 2–6

1 – oolitic limestone, 2 – massive carbonate beds, 3 – porous carbonate, travertine, 4, 5 – fine-grained carbonate with calcareous matrix, 6 – greyish clay, 7 – lake marl, 8 – conglomerate, 9 – fine-grained conglomerate, 10 – gravelly loam containing occasional pebbles, 11 – coarse-grained sand, 12 – medium-grained sand, 13 – fine-grained sand, 14 – massive sand without lamination, 15 – calcareous crust, duricrust, 16 – $CaCO_3$ content, 17 – $MgCO_3$ content, 18 – calcite content, 19 – CaO content, 20 – MgO, 21 – horizontal bedding, 22 – cross bedding, 23 – ripple-cross lamination

Sedimentary features to the Fig. 2–6 ➡



The upper part of the outcrop consists of more consolidated calcareous deposits - duricrust, which probably originated during an arid climate.

The section of Tepličky (TE) is shown on figure 5. The section occurs west of the village in the valley about 500 m from the church. The outcrop consists of coarse-grained sand layers and fine-grained gravel. Pale-brown and brown coloured fine-grained gravel contains clasts up to - 1.5 cm. The sand contains interlayers of lithified conglomerate with carbonate clasts up to 5 cm in diameter, clay intraclasts of ocherous-yellowish colour and spheric concretion of Fe up to - 0.5 cm, too (Fig. 4).

At the base of the outcrop consolidated coarse-grained sandstone occurs. It consists of quartz and feldspar clasts lithified by calcite. Locally mica and calcite clasts also occur. Organic matter does not occur in the sandstone.

The section Piesočnica near Behynce (P) is shown figure. 6. The outcrop occurs about 1.5 km SW of the village of Behynce. It is the largest and most extensive outcrop in the area with coarse- to fine-grained sand beds. The sand is gray-white and ocherous-brown and is medium sorted. Black claystone intraclasts occur between the beds No. 10 and 11.

The upper part of the outcrop consists of fine-grained gravel containing quartz and carbonate clasts, kaolinized rocks and calcareous concretions (Photo 8).

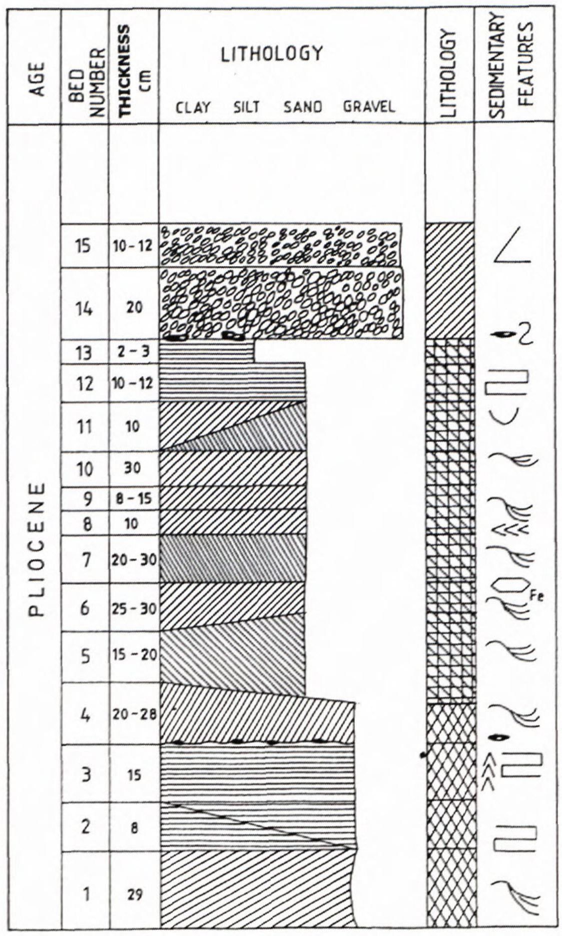


Fig. 3 Section of Dolné Otrokovice DO/2

Sedimentologic features, transport directions

The Volkovce Formation consists of gravelly and sandy fresh-water sediments deposited from suspension in lacustrine and fluvial environments. Sedimentary structures are mainly represented by cross bedding and less by trough bedding.

The deposits are conspicuously cross- and trough bedded at outcrops nearby Dolné Otrokovice (DO/1, DO/2, Figs. 2 and 3, Photos 2 and 3). The dip direction of inclined laminae in the cross-laminated deposits suggests transport direction from NW to SE. The laminae dip varies from 15° to 25°.

At the outcrop DO/1 in the bed No. 6 (Fig. 2), 30 cm deep and 1.10 m wide erosional channel was found (Photo 1). The channel axis has a 28° dip, the direction of the axis is from NW to SE. The channel is filled by medium-grained sand with occasional floating clasts (relict of lag deposits) passing in the upper part of the channel into fine-grained sand. The internal structure of the channel comprises conspicuous trough cross bedding. Loading is frequent on the lower bed planes of coarse-grained sand.

Hydroplastic deformation manifested by water-escape structures occurs on the right side of the sand pit. Most likely it reflects passive liquefaction in unconsolidated sediment which could be triggered by minor tectonic activity.

On the left side of the sand pit a layer consisting of medium-grained, weakly-consolidated sandstone overlies fine-grained gravel. At the base of the bed small clasts up to 1.5 cm in diameter and rip-up clasts of greyish claystone occur. The sandstone layer has an irregular channel form and it probably originated by erosional action of a stream on an at yet not consolidated underlying gravel, resulting in scour formation.

The deposits occurring at the Tepličky (TE) outcrop are characterized by faint normal grading shown by a prevailing coarse-grained sand of light-brown colour in the upper part of the profile and a fine-grained gravel having the clasts up to - 1 cm in diameter in the lower part . The fine-grained gravel is matrix-supported. The matrix is composed of medium-grained sand. The deposits are horizontally and cross laminated (Photo 4).

According to the direction of the cross laminae, the palaeoflow direction was from NW to SE. The laminae dip varies from 12° to 22°.

A subtle normal gradation occurs in individual beds. Chaotically arranged calcareous concretions up to 5 cm in size (Photo 4), Fe concretions, clay intraclasts and rip-up clasts originating from thin layers torn by water flow occur throughout the entire outcrop.

At the base of the outcrop or beneath the outcrop well-rounded clasts of weakly consolidated coarse-grained sandstones up to 15 cm in diameter occur.

At the sand pit of Piesočnica sand is horizontally and planar cross bedded (Photo 5). In the thick layers of sand trough cross bedding is locally preserved. Herring-bone

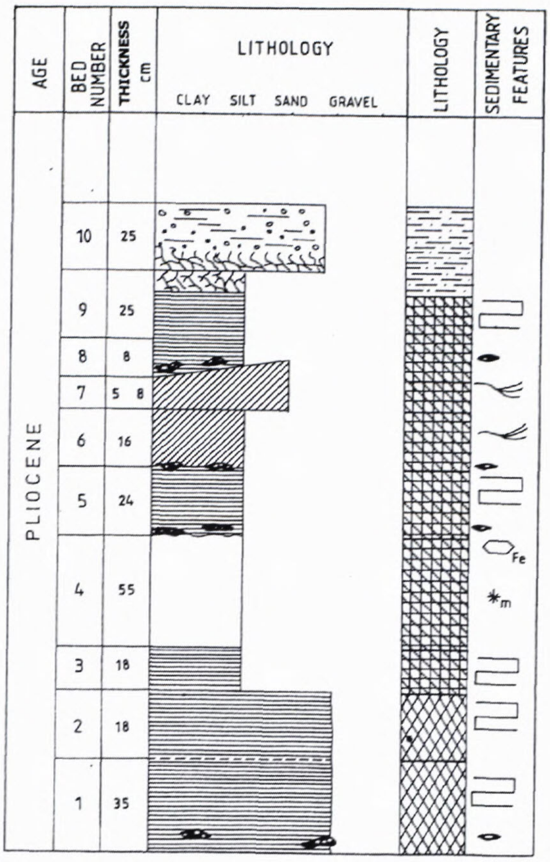


Fig. 4. Section of Dolné Trhovište DT

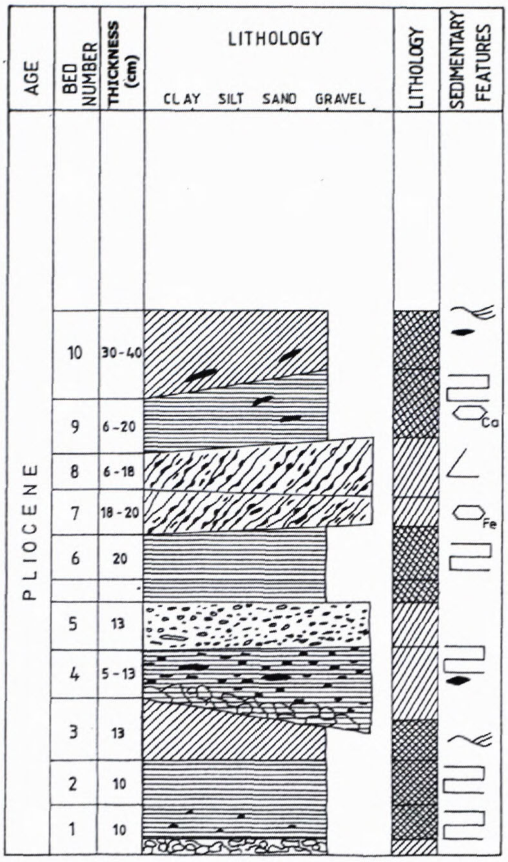


Fig. 5. Section of Tepličky Te (n = 27)

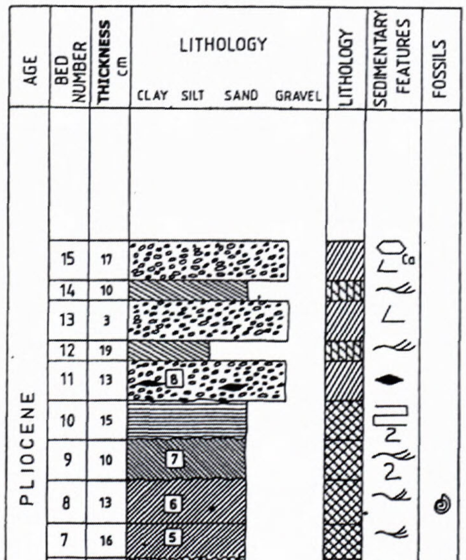
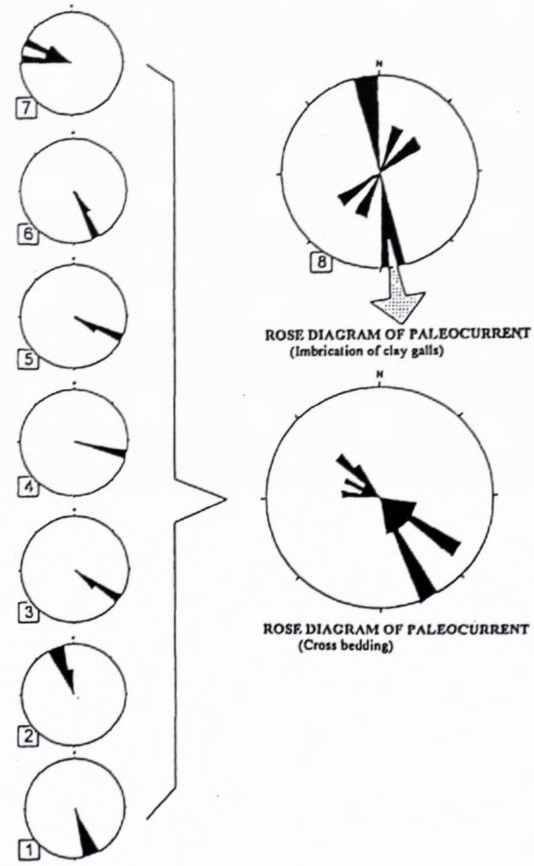


Fig. 6. Section at Piesočnica P (n = 35)



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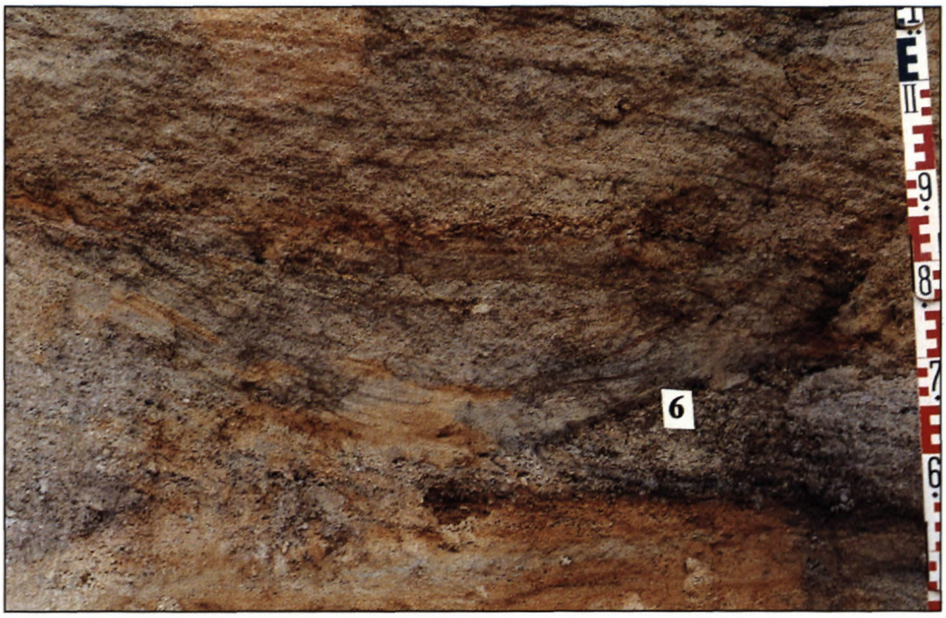

Photo. 1. Erosive channel. (profile DO/1, layer 6).

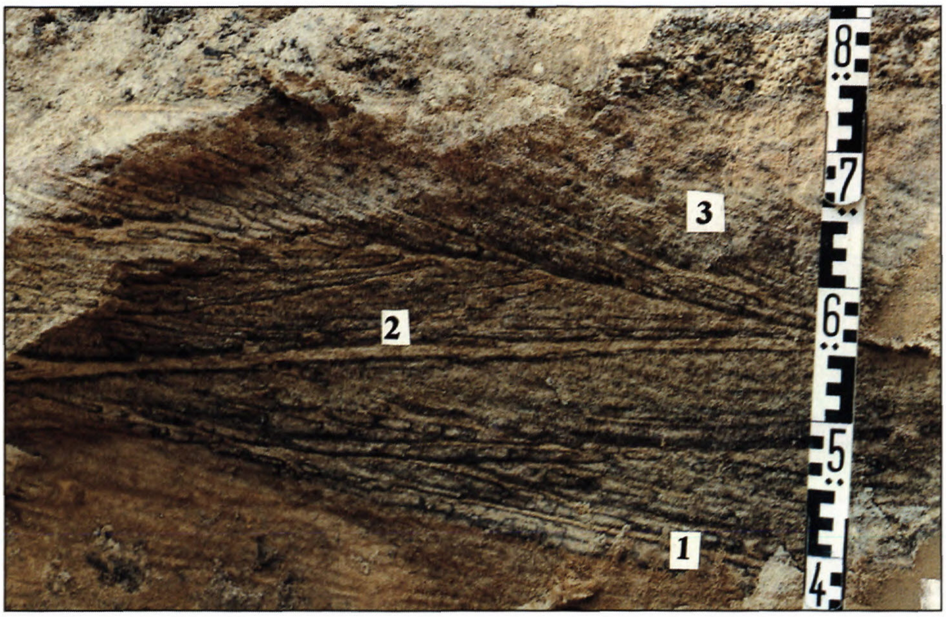

Photo 2. Cross - bedding. (profile DO/1 layer 1,2 and 3).

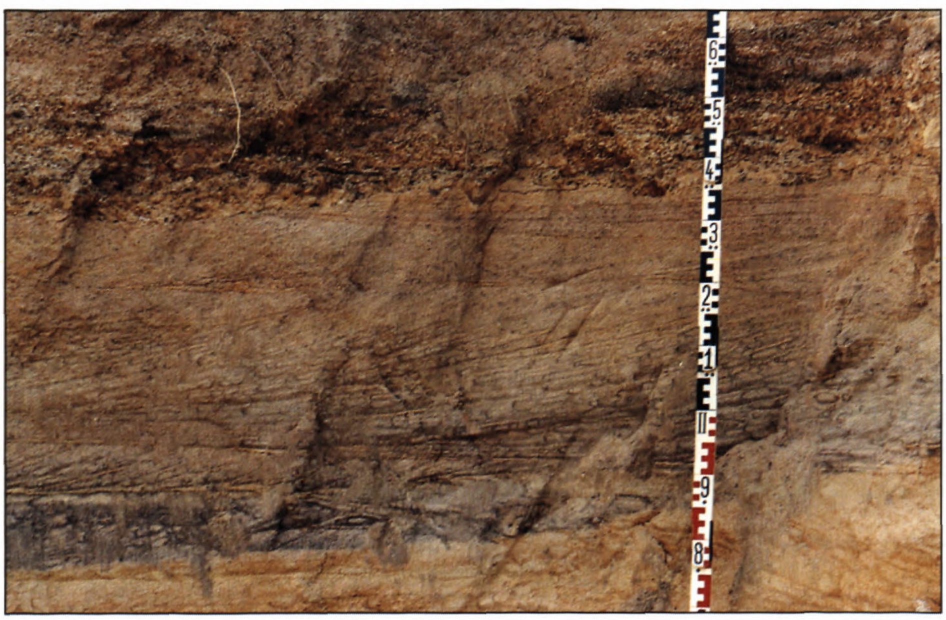

Photo.3. Planar cross – bedding. (profile DO/1 layer 5).

Photo. 4. Cross – bedding of sands. Carbonate nodules (Ř 1 – 3cm) are occurred in sands. (profile Te).

Photo. 5. Delta front characteristic of thick bodies of cross – bedded sands. (profile P, layer 6).

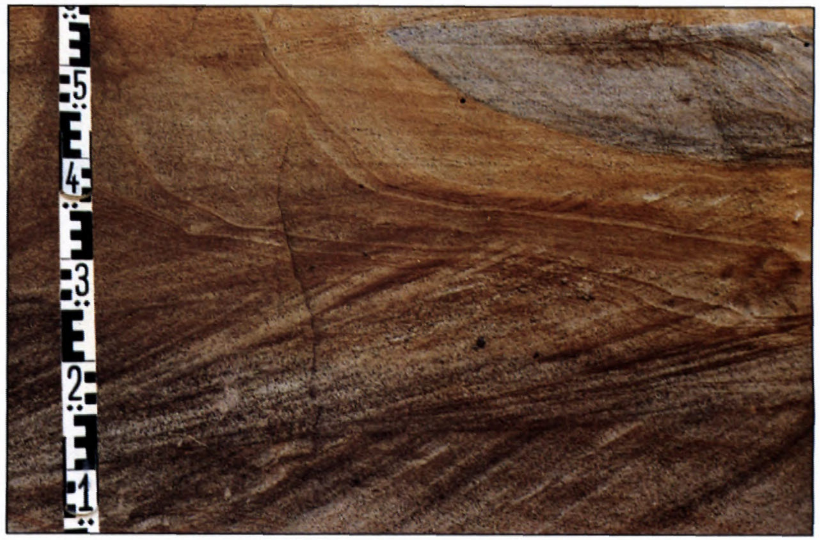

Photo. 6. Bimodal bedding of sands. (profile P, layer 2 – 3 and 8 - 9).

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Photo. 7. Imbrication of clay galls. (profile P, layer 8).

Photo. 8. Fine – grained gravels interlaminated with sands. Rip – channel and synsedimentary tectonic are visible. (profile P, layers 11 – 15).

Photo. 9. Synsedimentary faults. (profile Dolné Trhovište).

cross bedding also occurs. It originated by flows with different orientation resulting in bidirectional appearance (Fig. 6, beds No. 2 – 3 and 8 - 9, Photo 6).

The transport direction is from NW to SE. The laminae dips vary from 12° to 20°. Imbricated clay intraclastsindicate transport consistent with the direction of cross laminae (Photo 7).

Interesting is the occurrence of liesegang rings over the entire outcrop. They originated during diagenetic processes by reduction of Fe oxides and they colour sand into ocherous-yellowish and brown colour. Clasts of black claystones containing organic plant remnants were found between the beds 10 and 11. In the left part of the outcrop the upper section is composed of fine-grained, clast-supported gravel alternating with layers of coarse-grained sand. The base of the sand beds is loaded with hydroplastic deformations resulted from water escape.

The section near Dolné Trhovište (DT/1) consists of prevailingly horizontally laminated deposits, only the sand in the beds No. 6 and 7 is cross-bedded (Fig. 4).

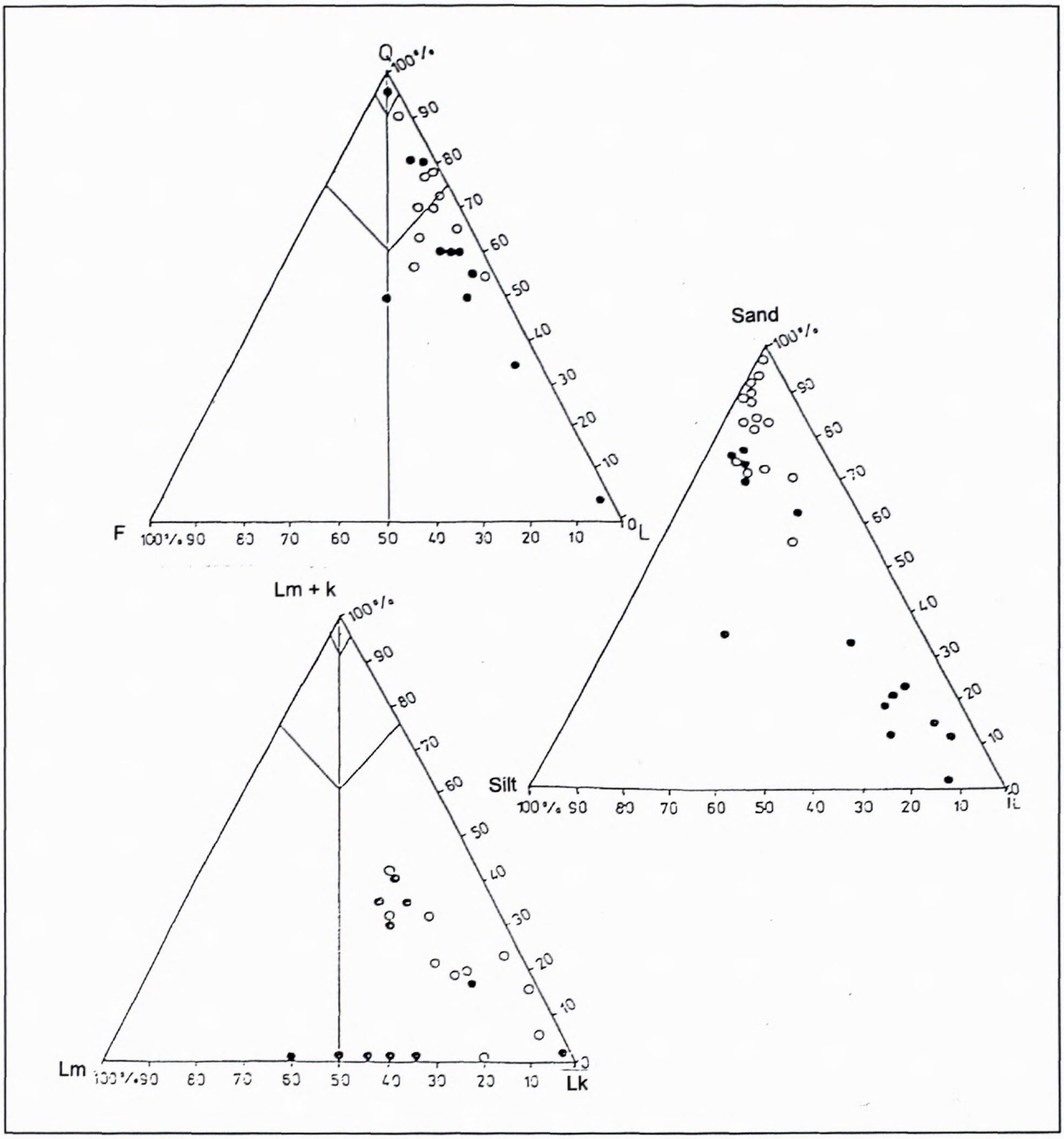

Fig. 7. QFL diagrams of minerals in sands. (after Pettijohn, Potter, Siever 1972).
Q – quartz, L – lithic grains (micas + carbonates), F – feldspar, Lm – lithic micas, Lk – lithic carbonates, L = Lk + Lm.

The dip direction of the cross laminae is toward the SE. At the base of the beds No. 5 and 6 rip-up clasts of ocherous-yellowish colour occur. The beds commonly contain small concretions (max. 0.3 cm) of Fe oxides colouring the sand to an ocherous-yellow. Horizontal lamination of sand is emphasized by an alternation of pale-brown, ocherous and grey coloured laminae. The colour is determined by the heavy mineral (ilmenite and limonite) content.

In the left part of the outcrop sand beds are deformed by synsedimentary faults with small throws suggesting minor tectonic activity (Photo 9).

Grain-size analysis of sand

Sand consists of fine- to coarse-grained fractions. The grain-size analyses showed occurrence of fine-grained gravel (0.07 - 23.28%) and coarse-grained sand (0.05 - 46.39%). The essential part of the sand is composed of medium-grained (1.02 - 74.83%) and fine-grained sand (7.41 - 72.16%). The silt content is 6.7 - 24.1%. Clay admixture is absent.

The grain size parameters (Mz, So, Sk, Kg) were calculated according Folk and Ward (1957). The median was calculated after Trask (1930).

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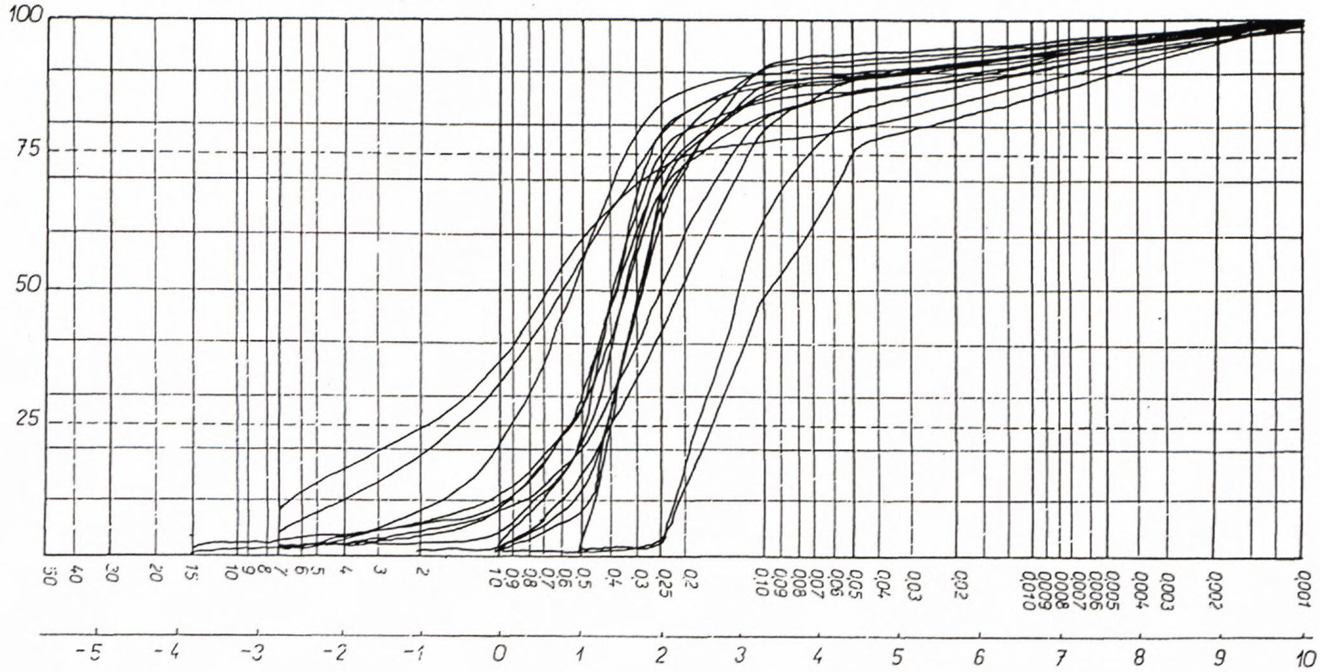

Fig. 8. Cumulative curver of sediments from localities at Dolné Otrokovce, Dolné Trhovište and Piesočnica.

The mean grain size (Mz) is 4.1 - 0.93 ϕ, the values in mm varies from 1.56 - .1 mm.

The median (Md) varies from 0.097 to 0.68 mm. The median shows mean grain size of deposits because the half of grains is smaller and the half of grains is larger than the grain size represented by median value. We infer it by reading of 50-percentile on cumulative curve.

The sorting coefficient (So) ranges from 1.1 to 2.08. According to cumulative curves the studied sand is of average sorting (Fig. 8).

Positive values of asymmetry (Sk) of the cumulative curve determine fine-grained and the negatively coarse-grained part of the sample. The positive values of the curve asymmetry range from 0.3 to 1.15 and they suggest fine-grained deposits. The curtisoity (Kg) of the curve, showing grain size distribution, is defined by the ratio between the spread in its central and marginal part. If the curve is steep (leptocurtic), fine grained clasts prevail in a coarse-grained fraction. On the contrary, if the curve is flat (platycurtic), fine-grained clasts prevail. The values of curtisoity range from 1.14 to 4.15, and they suggest leptocurtic to extremely leptocurtic curves. The higher degree of sorting may suggest an admixture of sandy deposits, which was already reworked before in a water environment somewhere.

Mineral content of sand

The sand clasts from the study localities are mainly surrounded to well rounded. Quartz prevails among the light minerals (55 - 90%). The quartz grains are coated yellow limonite. Abundant mica is also visible macroscopically. Feldspars abundance is 1.7 - 27.2%. The carbonate content varies from 0.02 - 20%. The mineral content suggest prevailing quartz and sublitic sand (Fig. 7) while in the sublitic sand carbonate and mica prevail. According to high content of quartz the quartoze sand represent a mature sediment.

The sand of the study localities also contain β quartz, indicating a volcanic origin. The closest occurrence of volcanic rocks is in the Middle Miocene Ruskovce Formation (Kováč et al., 1993) in the Bánovce depression located N of the study area. Taking into account the transport direction (from NW to SE), it is most probable that that formation was the source area for β quartz

Heavy minerals in sand

The association of heavy minerals was analysed from the samples taken from the localities of Dolné Otrokovce and Piesočná near Behynce.

The total heavy fraction content ranges from 0.2 - 0.92% (Tab. 3, Fig. 9). The mean values of heavy mineral content are shown in the table 4 and depicted in figure 10. The magnetic fraction with magnetite is totally absent. In the dia magnetic fraction rutile prevails from 7.1 - 23.4%. Zircon is abundant - from 2.06 to 9.6%. Apatite (0.5 - 7.9%), silimanite (0.1 - 2.6 %) and disten (1.3 - 8.6%) occur less frequently. In the para magnetic fraction ilmenite (5.3 - 90%) prevails. Tourmaline occurs in minor amount (7.3 - 17.6%).

At Piesočnica garnet (18.1 - 24.7%) and epidote (14 - 20.4%) prevail. At other localities the garnet content was lower (1.0 - 4.1%) and epidote was absent. Hematite was only found at Dolné Otrokovice (4.8%).

We calculated the ZTR index from the percentual content of zircon, tourmaline and rutile. The index shows a mineralogic maturity of the heavy mineral associations in sand. The ZTR index value is 42 - 96%, suggesting a mature sand.

Tab. 3. Content of heavy minerals in sands

Pattern	1/DO	2/DO	3/DO	4/DO	1/DO2	2/DO2	6a/DO	6b/DO	4/P	5/P
Fraction	0, 25 - 0, 1	0, 25 - 01	0, 25 - 0, 1	0, 25 - 01	0, 25 - 0, 1	0, 25 - 01	0, 25 - 0, 1	0, 25 - 01	0, 25 - 0, 1	0, 25 - 01
Cont. of HM %	0, 39	0, 31	0, 20	0, 39	0, 45	0, 23	0, 57	0, 48	0, 92	0, 63
rutile	23, 3	22	20	7, 1	10, 5	23, 4	22	23	18, 1	10, 9
zircon	18, 6	15	14	14, 4	9, 6	15, 8	18, 6	20, 6	12, 5	12, 3
apatite	4	3	7, 9	0, 5	1, 9	2	2, 6	1, 3	2, 1	1, 7
sillim.			2, 4	0, 1			2, 6	0, 6	0, 8	0, 7
distene	3	8, 6			2, 4	1, 3	4	2	3, 8	
zaphire										
gold										
ilmenite	30, 6	30	20	51, 2	48	20, 6	90	5, 3	11, 2	10, 9
limonite	10	4, 6	12, 1	3	7, 6	11	10	27, 3	9, 4	6
tourm.	16, 6	12	17, 6	16, 9	16, 8	16, 5		13, 3	8, 1	11, 3
garnet		2	3, 6	1	2, 8	4, 1		2, 6	18, 1	24, 7
epidote									15, 5	20, 4
hematite						4, 8				
ZTR index	89	78	81	96	83	88		90	49	42

Tab. 4

min	rutile	zircon	apatite	sillim.	distene	zaphire	gold	ilmenite	limonite	tourm.	garnet	epidote	hematite	magnetite	n
A	6, 07	11, 87	2, 3	5, 71	0, 53	0, 11	0, 04	41, 64	16, 3	3, 46	6, 9	3, 93	0, 41	4, 40	21
B	18, 3	15, 14	2, 7	0, 72	2, 51			31, 78	10, 1	12, 91	5, 89	3, 59	0, 48		10

The identified association of heavy minerals is typical for crystalline rocks. It is suggested by the occurrence of rutile, zircon, silimanite, disten and by the prevailing epidote and garnet in some samples. The increased content of ilmenite, similarly to β quartz, also may show that the source area had volcanic rocks.

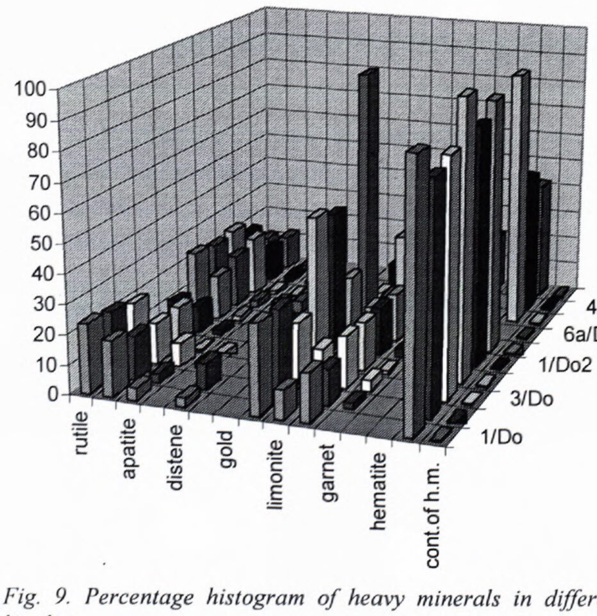

Fig. 9. Percentage histogram of heavy minerals in different localities

X - Ray analysis of clay

Clay rip-up clasts, which occurred between beds at localities Dolné Trhovište and Piesočnica, were RTG and DTA analysed. Smectite prevails in samples 1/DT from Dolné Trhovište and 6/P and 2/P from Piesočnica. The most abundant minerals are, then, illite and kaolinite. In the sample 3/P (Piesočnica) illite prevails; less frequent are smectite and chlorite. The sample 4/DT (Dolné Trhovište) contains smectite with an increased content of Na. However, the Na content was probably caused by natrium hexamethaphosphate added to the sample in order to prevent coagulation. Other minerals are illite and kaolinite.

Conclusion

The deposits of the Pliocene Volkovce Formation, represented by thick sand beds with a gravel admixture, were studied at several localities in the NW part of the Rišňovce Depression (Dolné Otrokovice, Dolné Trhovište, Teplička and Piesočnica).

The sand is mainly medium to fine-grained and it is well sorted (coefficient of sorting 1.1 to 2.08).

An imbrication of rip-up clasts occurs in the cross bedded sand. Vector measurements of clay imbrication support that the palaeoflow direction is from NW to SE.

Brown to ocherous coloured upper part of beds suggest that the influence of oxidation due to water level fall. Except for the rarely occurring redeposited clasts of black claystones with a high content of organic matter, which represent eroded swamp deposits, the deposits do not contain any organic matter.

Cross bedding and trough cross bedding is typical for the sand. Beds with horizontal lamination and scours also occur. The direction of cross laminae show transport direction from NW to SE. Locally found opposite orientation of herring bone cross laminae is caused by flows with different direction.

From the viewpoint of mineral composition, smectite prevails and kaolinite, illite and chlorite occur in lesser amounts. Based on the mineral composition the sands are classified as quartz and sublitic sand with prevailing quartz and lithic rock fragments.

The heavy mineral associations with rutile, zircon, ilmenite, tourmaline, garnet, epidote, disten and silimanite suggest that the source area had crystalline rocks. According to the palaeoflow direction (from NW to SE) it probably is represented by crystalline rocks of Považský Inovec Mts. Most probably also rivers from Bánovce Depression, transporting β quartz and probably also illite from Ruskovce Formation, represented the path of sediment transport. High values of ZTR index suggest a relatively high sand maturity.

The continuing deposition, sufficient input of clastic material and probably also the absence of tectonic activity causing increased subsidence of the area of Rišňov Depression, show a progradational character of the delta. The delta probably joined south of the study area a lake occurring in the central part of the Danube Basin. The characteristics of the above described sandy deposits suggests their origin was in the delta plain represented by a wide channel.

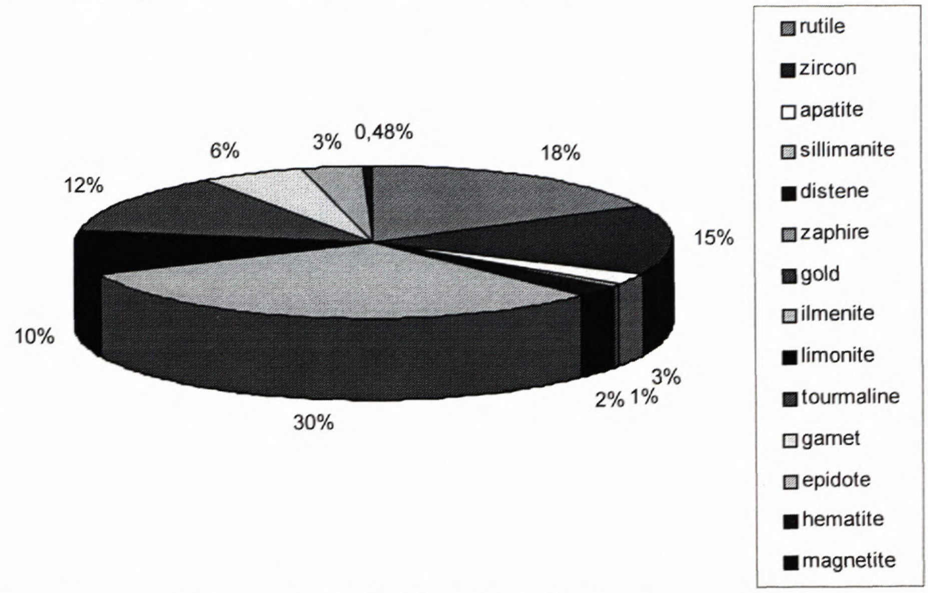

Fig. 10. Average contents of heavy minerals in different localities

Acknowledgements

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Results of paleomagnetic investigation on Permian rocks of the Hronic Unit (Western Carpathians, Slovak Republic)

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Abstract: The magnetostratigraphic investigation on the profile of the Upper Carboniferous-Permian rocks belonging to the Hronic Unit in the Nízke Tatry Mts. revealed occurrence of the first-order time marker, so called Illawara Reversal, near the boundary separating the 2nd and 3rd megacycles at localities of the Malužiná Fm.

Key words: Hronic multinappe Unit, Late Paleozoic magnetostratigraphy, Illawara Reversal

Introduction

The continental sequences of the Permian in the Western Carpathians are generally very poor in organic remnants determining insufficient radiometric data. The time period within the range of 300 – 250 Ma is prevailingly represented by clastic sediments and volcanics, which are preserved in the structure of Alpine units of the Western Carpathians in relics only. The analysis of these sequences has been carried out so far mainly by methods of lithostratigraphical analysis combined with biostratigraphical and isotope-geochronometrical methods. The objective of this paper is to put forward a more precise time scale of the Permian of the Hronic Unit by the method of magnetostratigraphy. The complete profile of Upper Carboniferous-Permian of the Hronic Unit in the Nízke Tatry Mts. was analysed by standard magnetostatigraphical methods. We choose localities in the Malužiná and Dikula Valleys (Fig. 1.) which consist of non-metamorphosed sedimentary complexes. At these complexes we assume preservation of primary remanent magnetic polarization. Moreover, these sequences are continuously preserved from the underlying Upper Carboniferous rocks to the overlying Lower Triassic rocks.

In Permian volcanic-sedimentary formations of the Western Carpathians the method of magnetostratigraphy has not been applied so far. In the preceding period the paleomagnetic investigation was carried out (the results published by Muška 1975-1988, Muška & Vozár 1987-1989, mainly in the frame of Project IGCP 5), but only used for the tectonic reconstructions. The amount of the data from individual lithostratigraphic units was not sufficient to be able to establish correlation with the magnetostratigraphic scale.

Geological setting

Late Palaeozoic volcano-sedimentary complexes in basal part of nappes of the Hronic Unit are denoted as the Ipoltica Group which consists of Nižná Boca and Malužiná Formations (Vozárová & Vozár, 1981). The tectonic basement of the Ipoltica Group, located in the Ipoltica and Dikula Valleys S of the Čierny Váh river on the northern slopes of the Nízke Tatry Mts., consists of the Veporic Unit, mostly of the Mesozoic of the Veľký Bok Group. The internal structure of the Ipoltica Group sequences is affected by the Alpine thrusting and faulting processes. Variable tectonic reduction is evident mainly in the sedimentary sequences of the Nižná Boca Formation.

Brief characteristics of lithostratigraphic units

Nižná Boca Formation. It is generally coarsening-upward siliciclastic sequence consisting of numerous small, repeating fining-upward sedimentary cycles. The vertical profile of the Nižná Boca Fm. indicates channel and overbank fluvial deposits originated in meandering rivers. The presence of lacustrine deposits suggests occurrence of lakes nearby rivers. The deposits are predominantly Gray and black. This fluvial-lacustrine and/or fluvial-deltaic and lacustrine association was interrupted by synsedimentary subaerial volcanism. It is manifested by abundant redeposited volcanogenic material mixed with non-volcanic detritus and with sporadic occurrences of thin layered dacitic tuffs as well as exceptionally dacite lava flows.

Macroflora from the uppermost part of the Nižná Boca Fm. proved the Stephanian B-C age (Sitár & Vozár, 1973). The palynological analysis of Planderová (1973) distinguished the Stephanian A-B and the Stephanian C-D microflora assemblages.

Malužiná Formation. The Permian sequence of the Malužiná Fm. is developed gradually from the underlying Nižná Boca Fm. It comprises a thick succession of redbeds (more then 2000 m in places) which consists of alternating conglomerates, sandstones and shales. Lenses of dolomites, gypsum and calcrete/caliche horizons occur locally. Fining-upward cycles in the order of several me-

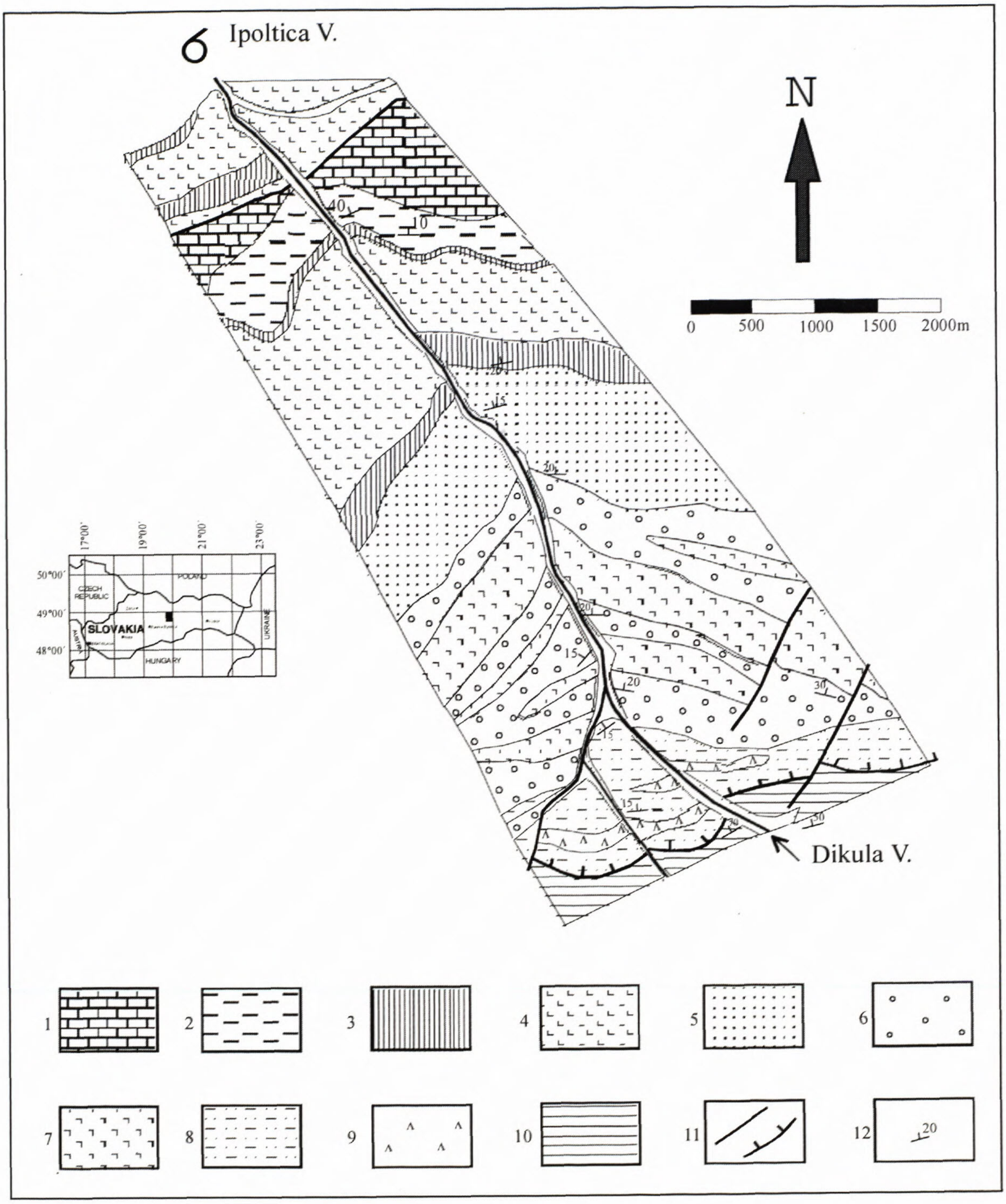
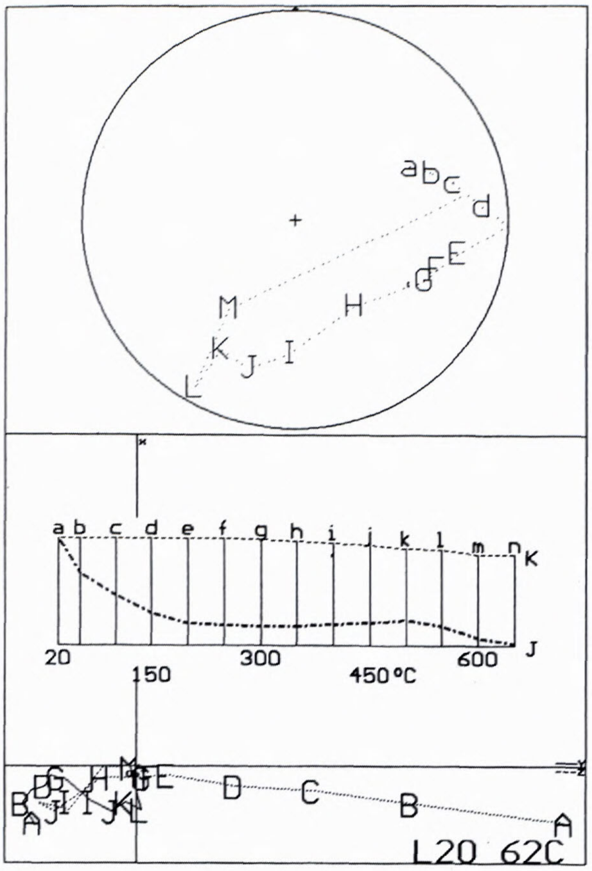
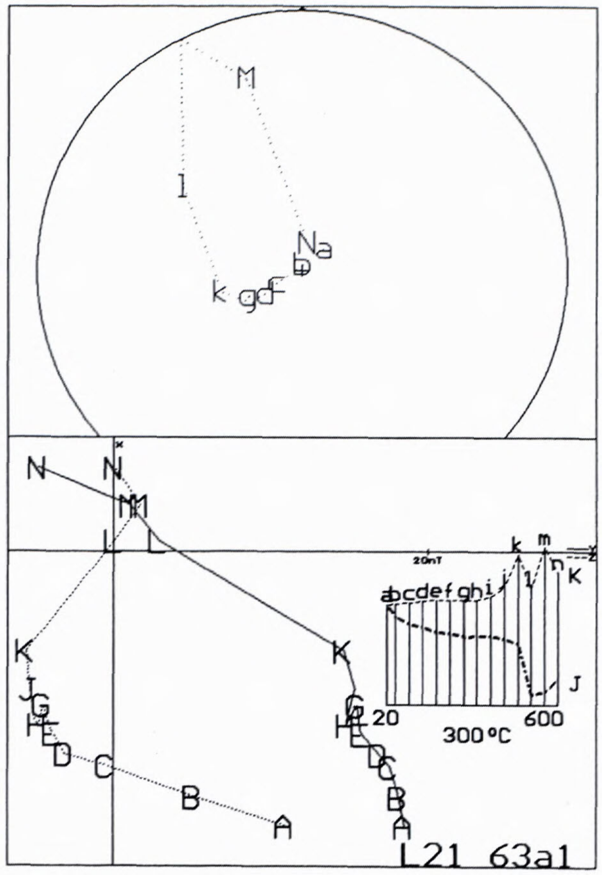


Fig. 1 Geological situation of the Ipoltica V. and Dikula V. (Northern part of the Nízke Tatry Mts.)
Explanation: Hronic Unit – 1. carbonate rock complex of Middle Triassic; 2. clastic sediments of Lower Triassic; 3 – 7. Malužiná Formation: 3. 3rd megacycle sediments; 4. andesite-basalts of 2nd eruption phase; 5. 2nd megacycle sediments; 6. 1st megacycle sediments; 7. andesite-basalts of 1st eruption phase; 8 – 9. Nižná Boca Formation: 8. sediments; 9. dioritic sills and dykes of Permian in age; Veporic Unit – 10. Mesozoic sediments of the Veľký Bok sequence; general explanation: 11. faults; overthrust lines, 12. schistosity, foliation

ters, as well as three regional megacycles arranged above each other, are typical. The polyphase synsedimentary andesite-basalt volcanism is the further significant phenomenon. Fossil remnants of the channel bar and point bar deposits associated with flood plain and natural levee sequences are dominant in the lower part of the three megacycles. A playa and inland sabkha/ephemeral lake association was identified in the upper part of the megacycles. The deposits of the Malužiná Fm. were deposited mainly in fluvial and fluvial-lacustrine depositional system during permanent semiarid and arid climate.





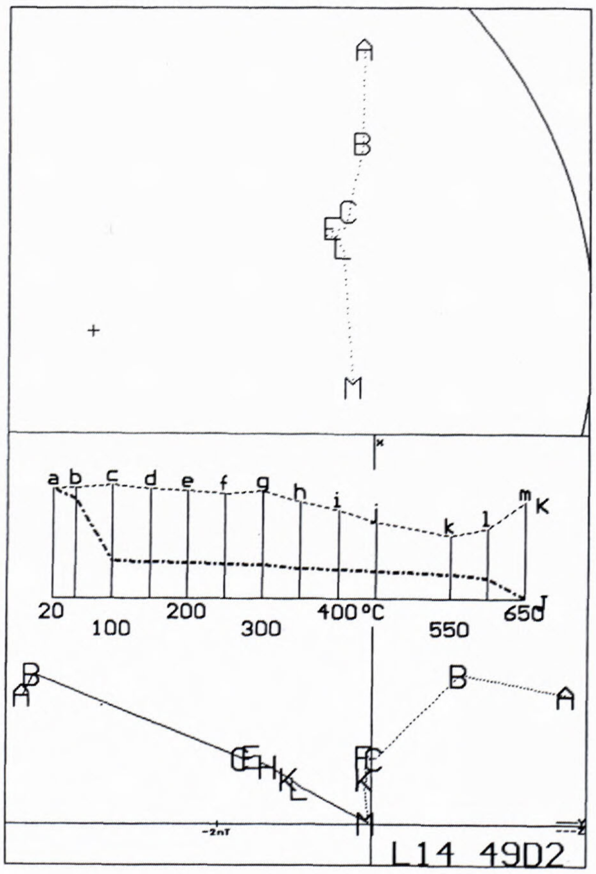


Fig. 2. The examples of demagnetization graphs of the samples No 62C from loc. L 20, No 63A1 from locality L 21 and No 49D2 from locality L 14. Thermal demagnetization curves: dashed line – volume magnetic susceptibility; bracked line – remanent magnetic polarization.
Zijderveld-diagrams of the XY and XZ components. Stereographic projections of the thermal cleaning course: the small letters - mean reversal magnetic polarization; the capital letters – normal magnetic polarization.

The microflora proved the Lower and Upper Permian age of the Malužiná Fm. The following assemblages were described by Planderová (in Planderová 1973 and Planderová & Vozárová, 1982): 1. The Autunian assemblage, corresponding approx. to the sediments of the 1st megacycle; 2. The Autunian-Saxonian assemblage, specifying age of the 2nd megacycle; 3. The Thuringian assemblage, determining age of the third megacycle sediments.

In the upper part of the 2nd megacycle a local lithostratigraphic member was defined – the Kravany Beds. They consists of gray and greenish-gray sandstones and siltstones with locally redeposited plant debris and thin uranium-bearing horizons. The Autunian-Saxonian microflora assemblages correspond approximately to the 1st and 2nd megacycles. This assumption is supported by $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ dating of 236 and 274 Ma from uranium-bearing layers (Lepka in Rojkovič et al. 1992).

Magnetostratigraphic measurements

The 351 rock samples from 23 outcrops of investigated profile were elaborated. Each sample was undergone thermal magnetic cleaning. Paleomagnetic measurements were carried out in Paleomagnetic laboratory of the Geophysical Institute SAS Bratislava. The demagnetization step of 50 °C from the natural stage till to 650 °C was used. The remanent magnetic polarization as well as volume magnetic susceptibility were measured after each demagnetization step. Thermal cleaning was performed into MAVACS – system, magnetic polarization was measured on spinner magnetometer JR-5 and volume magnetic susceptibility on cappa-bridge KLY-3. The demagnetization graphs, so called Zijderveld-diagrams of XY and XZ components and stereographic projection of the remanent magnetization vectors was performed. Mean paleodirection of each locality (outcrops) was calculated using the Fisher statistics (Fischer, 1953).

Characteristic paleodirection of measured sample was chosen according to demagnetization graphs (Fig. 2). The smooth part of the magnetic susceptibility curve indicated that no phase transition of magnetic mineral occurred in rock sample. We supposed that after several first thermal steps the secondary, probably viscose, magnetic polarization was released. Convergention of the paleodirections on stereoprojection as well as on Zijderveld-diagrams was also criterion for choosing of characteristic direction. Several samples with the large dispersion of the remanence directions were rejected.

In efforts to choose as probable as possible paleodirection we analysed the four variants of characteristic directions.

Discussion and conclusion

The results are summarized in a schematic magnetostratigraphic profile for the Late Palaeozoic of the Hronic Unit (Fig. 3). In the Upper Carboniferous, the reversal pattern has been extended into the whole profile in the Dikula Valley. The mean values of magnetic inclination is ranging from –30° to –40°. The set of measured samples from both Upper Carboniferous localities is characterized by reversely and homogeneously magnetized rocks. Indication of normal polarity were found close to the Nižná Boca Fm./Malužiná Fm. boundary (loc. NT-3). Within the 1st and 2nd megacycles of the Malužiná Fm. sediments both normal and reversal magnetization have been found besides some inhomogeneous samples. Prevalent part of sediments is characterized by reversal polarity with the mean inclination between 0° and -30°. Several normal magnetized horizons were found. The mean positive inclination within the 1st and 2nd megacycles varies between 0° and +45°.

We assume, despite of this uncertainty, that the sediments of the Nižná Boca Fm. and the 1st and 2nd megacycles of the Malužiná Fm. belong to the Carboniferous-Permian Reversed Megazone (Menning, 1995; formerly the Kiaman Magnetic Interval - Irwing & Parry, 1963, later abandoned by Irwing and Pullaiah 1976 and replaced by the Permo-Carboniferous Reversed Superchrone). Within the Carboniferous-Permian Reversed Megazone (CPRM) were described several normal zones (according to Menning, l.c. at least five horizons). Two were identified near the Carboniferous-Permian boundary of the Transcaucasus succession (296 Ma; Khramov & Davydov, 1991). Two further normal zones are in the volcanics of Tholey Subgroup of the Saar-Nahe-Basin (291 Ma; Berthold et al., 1975). A fifth normal zone is in the Garber Sandstone (Oklahoma, about 280 Ma; Peterson & Nairn, 1971). Nevertheless, correlation of the Malužiná Fm. normal zones with those five zones is complicated due to absence of any radiometric dating.

There is evidence that in the uppermost part of the 2nd megacycle (Fig.3) a systematic change of the inclination occurs. A strong change in the inclination occurs at loc. NT-14 (Fig. 3). The mean value of inclination is shifting from +80 to negative inclination. This zone could be correlated with Illawara Reversal (IR). This assumption is supported by the radiometric data 263 resp. 274 Ma from the lithostratigraphical equivalent uranium-bearing horizon. IR is a first-order time marker estimated by Khramov (1963) within the Tatarian. According to Menning (1995) the age of the Illawara Reversal is 265 Ma.

Within the third megacycle of the Malužiná Fm. there are alternating reversed and normal polarity zones. They should be correlated with The Permian-Triassic Mixed Megazone Menning (1995).

The following facts underline the reliability of the results:

1. The magnetostratigraphic boundary represented by a strong change of polarity fall within lithological units.

2. The polarity determination in the whole complex of collected sediments is complicated. Additional

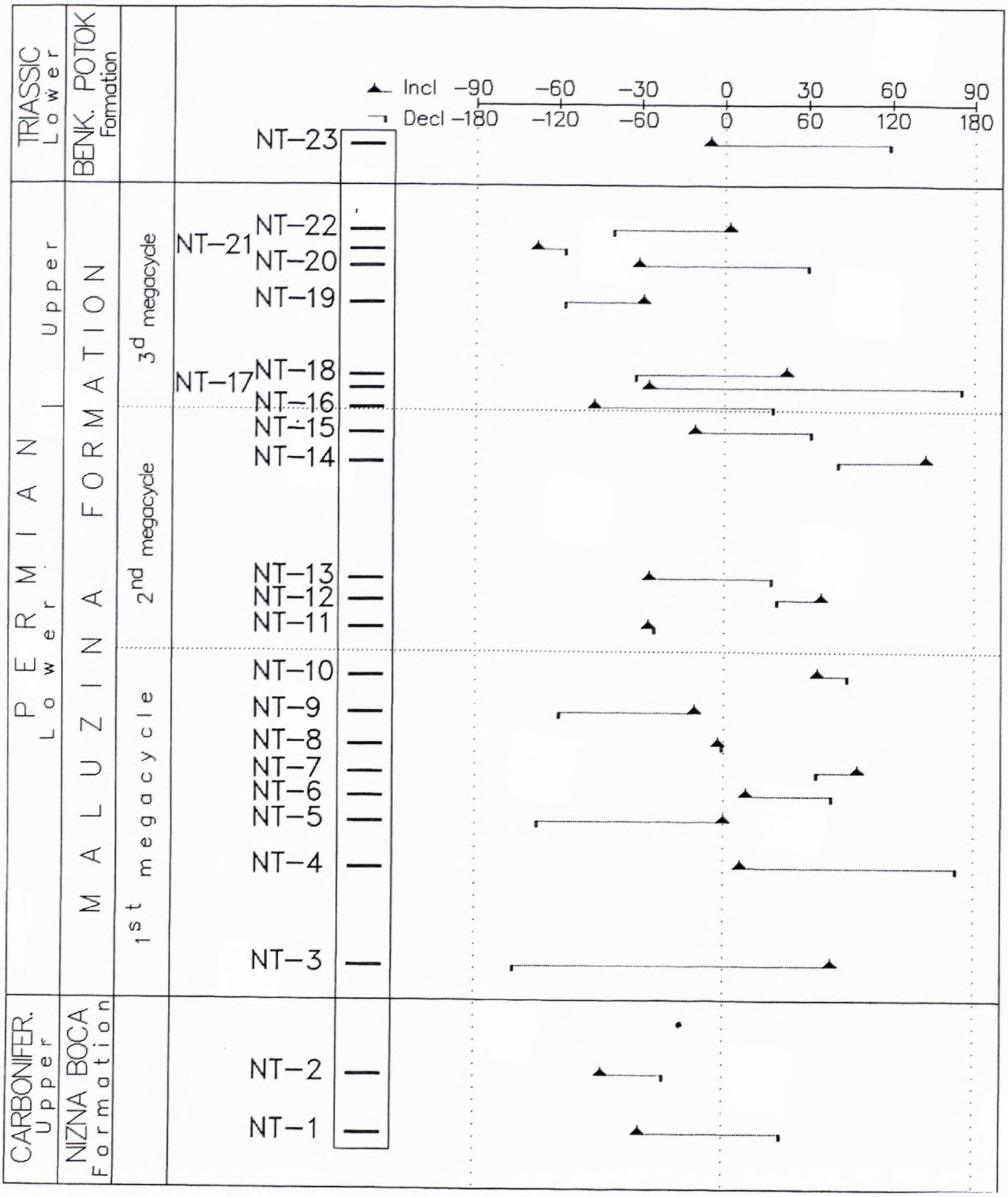


Fig. 3. Results of magnetostratigraphic investigation of the Late Palaeozoic Hronic Unit. Explanation: NT no – number of locality (outcrops); full triangle – mean magnetic inclination; perpendicular short line – mean magnetic declination.

investigations must be carried out using finer grained samples as far as possible and applying a detailed thermal ev. alternating field demagnetization.

3. The Autunian-Saxonian sequences are divided from the Thuringian of the Malužiná Fm. by strong change of polarity confirming by the Illawara Reversal.

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