# SLOVAK GEOLOGICAL MAGAZINE

VOLUME 4 NO 1 ISSN 1335-96X



Geological Survey of Slovak Republic, Bratislava
Dionýz Štúr Publishers

1/98

ISSN 1335-96X

# SLOVAK GEOLOGICAL MAGAZINE

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**The journal is focused on problems of the Alpine-Carpathian region.**



**Managing Editor**: G. Šipošová
**Language review and translation:** H. Drewes, B. Molák
**Technical Editor:** G. Šipošová
**Address of the publishers:** Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovakia
**Printed at:** Gupress Bratislava
**Pri**
**Annual subscription rate** ... postage

Manuscripts were acc ... 98

# SLOVAK GEOLOGICAL MAGAZINE

VOLUME 4 NO 1

ISSN 1335-96X



GEOLOGICKÁ SLUŽBA SLOVENSKEJ REPUBLIKY
DIONÝZ ŠTÚR
1827-1893

Geological Survey of Slovak Republic, Bratislava
Dionýz Štúr Publishers

1/98

# Suprafan and channel-and-levee deposits near Tichý Potok, Levoča Mts.; Central-Carpathian Paleogene Basin, Slovakia

JURAJ JANOČKO[1], BOHUMIL HAMRŠMÍD[2], STANISLAV JACKO[1] and ZUZANA SIRÁŇOVÁ[3]

[1]Geological Survey of Slovak Republic, P.O.Box 13, 04 01 Košice, Slovakia
[2] Moravské Naftové Doly a.s., 69530 Hodonin, Czech Republic
[3] Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovakia

***Abstract.*** Deposits in the Levoča Mts. represent the uppermost part of the Central-Carpathian Paleogene Basin fill. The biostratigraphical analyses reveal plankton of NP 25 and NN 1 zones suggesting a Late Oligocene - Early Miocene age. The deposits originated in a submarine fan channel-and-levee and suprafan (apron) subenvironments. Channel-and-levee deposits are composed of thick-bedded sandstones (channel fill) and alternating thin beds of sandstones and shales (levee deposits). Their thickness is as much as 40 m. Suprafan deposits consist of thick, mostly massive and normal-graded sandstones and sparse pebbly sandstones and conglomerates. They are as much as 150 m thick. The correlation of deposits in sections and boreholes suggests alternation of the two types of deposits which was probably caused by fluctuation of the sediment input into the basin as well as tectonic activity on the basin margins.

***Key words:*** West Carpathians, Paleogene, turbidites, suprafan, apron, channel-and-levee deposits

## Introduction

The Central-Carpathian Paleogene Basin (CCP Basin) is one of the most potential economic areas in Slovakia for hydrocarbon accumulations and hydrothermal prospects. Suitable hydrocarbon source rocks are present and geological structure and facies changes are favorable for potential hydrocarbon reservoirs. Numerous studies were done in the area in the last three decades. The studies were aimed at both basic research and economic prospects which were later drilled (e.g. Marschalko, 1964, 1968, 1970, 1978, Leško et al., 1982, 1983, Koráb et al., 1986, Janků et al., 1987, Rudinec et al., 1988, 1989, Nemčok et al., 1996, Soták et al., 1996). The sedimentologic investigation of Marschalko (1964) suggested the still valid concept of prevailing deep-water deposition by gravity flows during the basin history. The last comprehensive study of the eastern part of the CCP Basin has included both a geologic map of the area at a scale 1:25 000 (Gross et al. 1996) and the assesment of the area for hydrocarbon potential (Soták et al. 1996).

The report gives preliminary results of a sedimentological study of the thick sandstone bodies of the CCP Basin fill. Extensive hydrogeological drilling in the past years and well exposed outcrops near Tichý Potok village located in the Levoča Mts. (Fig. 1) provided data for sedimentological evaluation. The main objective of this study is to document the facies succession and biostratigraphy in drillholes and outcrops near Tichý Potok village. Interpretation of depositional environment has been made on the basis of the data obtained.

## General geological setting

The CCP Basin lies in the northern part of the Slovakian Inner West Carpathians (Fig. 1). To the south it is bounded by the pre-Paleogene, Mesozoic and Paleozoic formations of the Inner Carpathians. In the north it is separated from the Outer-Carpathians Flysch zone by the Pieniny Klippen Belt (Fig. 1). The basin is developed as a forearc basin on the proximal part of the accretionary wedge above the southwestward subducting oceanic slab attached to the European Platform. The kinematic history of the basin is complex and is connected with the escape tectonics of the North-Pannonian unit caused by the oblique subduction of the oceanic crust of the Outer Carpathian Flysch trough beneath the North-Pannonian unit (Csontos et al., 1993). Because the basin lies on the rigid block, strata deformation is minimal. The pre-Paleogene areas of the Tatra and Čierna Hora Mts. forming "islands" in the CCP Basin (Fig. 1) are the result of postdepositional uplift. The elongated, crescent-shaped basin is about 200 km long, the maximum width is about 60 km. The maximum thickness of deposits in the basin is about 4 000 m and their local preservation depends on the post-depositional tectonic history. The vitrinite reflectance data done on the samples from the north-eastern part of the basin (borehole PU-1) suggest the removal of 1.5 to 2 km of overburden deposits (Franců & Müller, 1983).

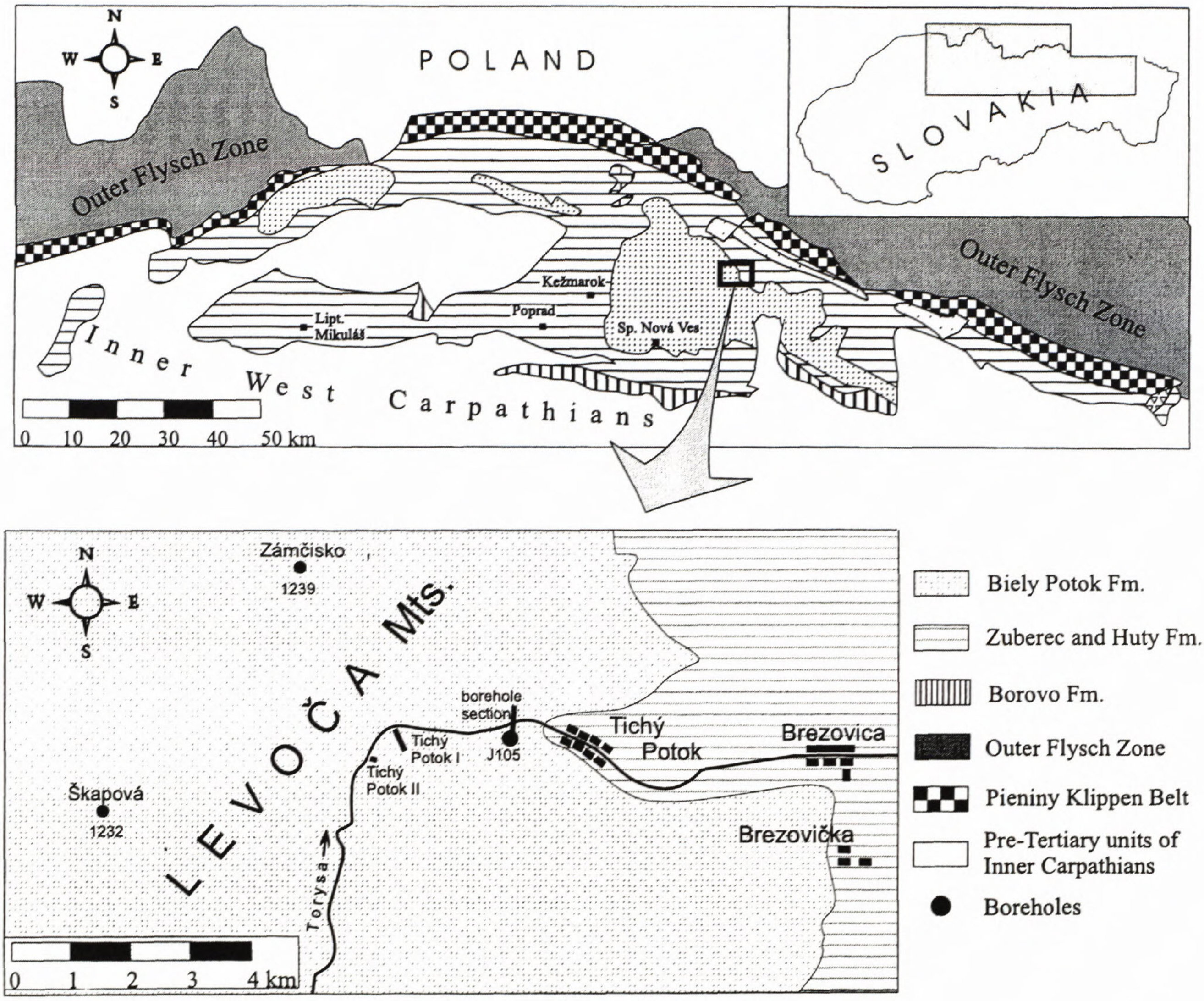



*Fig. 1: Map of the studied area showing location of the outcrops and boreholes. The map showing geological units and Central-Carpathian Paleogene Formations is constructed after Biely et al. (1996).*

Deposits in the CCP Basin comprise the Subtatric Group consisting of four formations (Fig. 2, Gross, Köhler & Samuel, 1984) deposited in shallow (Borové Fm.) and deep-marine environments (Huty, Zuberec and Biely Potok Fms.).

The lowermost Borové Formation consists of a basal terrestrial deposits (mainly alluvial fan and lacustrine) and shallow-marine transgressive deposits. The age of the formation is Middle and Late Eocene (Ypressian to Priabonian), the lowermost terrestrial deposits might have been deposited during the Late Paleocene and Early Eocene (Gross in Polák et al., 1992). The time-transgressive character of the deposits and their areal distribution suggest the connection between the CCP Basin and the Outer-Carpathian Flysch zone during deposition. The Pieniny Klippen Belt was not elevated at the time of transgression or, at least, there were sea ways between the Outer-Carpathian Flysch zone and the CCP Basin.

The overlying Huty Formation (Late Eocene - Early Oligocene) consists of claystones and siltstones with minor interbedded thin sandstone or conglomerate beds. We believe the sedimentation of the Huty Formation was in the subenvironment of basin plain and outer submarine fan.

Zuberec Formation (Late Eocene - Early Oligocene) consists of alternating thin, laterally persistent sandstone and shale beds (rhythmical flysch). The formation occurs only in some parts of the basin where it overlies the Huty Formation. The deposits of this formation are thought to have been deposited in the subenvironment of an outer submarine fan. Recently, the thick (1 - 3 m) sandstone beds alternating with "rhythmical flysch" (zebra facies) were defined as a member of Zuberec Formation (Kežmarok beds, Gross, 1997). Kežmarok beds represents a mid-fan channel-and-levee subenvironment.

The Biely Potok Formation is the uppermost part of the basin fill. Our biostratigraphical analyses indicate a Late Oligocene - Early Miocene (NP 25 - NN1) age for the formation. The deposits mostly consist of sandstones and subordinate conglomerates and shales. According to

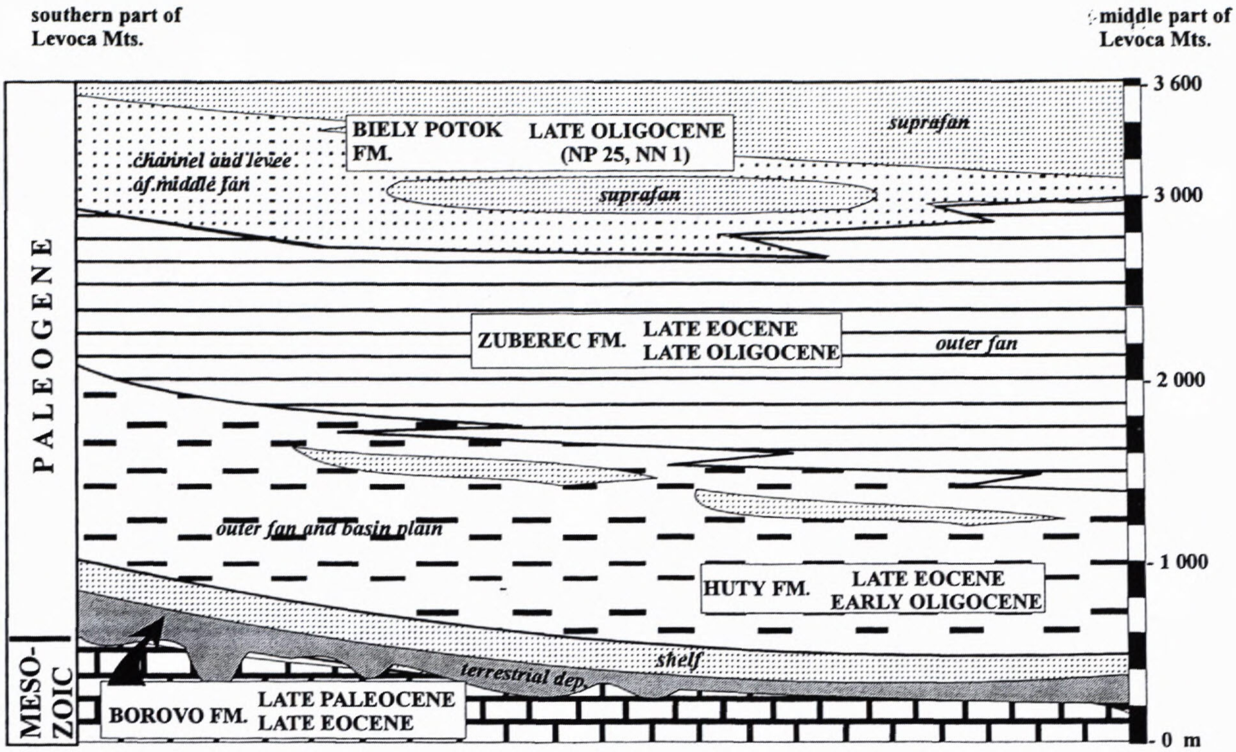



*Fig. 2: Lithostratigraphic column of the studied area.*

our observations the formation includes deposits laid down in suprafan lobes (aprons?), basin slope and possibly canyon subenvironments.

## Methodology

At the beginning of the work a few cross-sections through the entire basin were studied in order to evaluate the older interpretations and to define the main structure of the basin. After that our study has been focused on the investigation of the Biely Potok Fm. and the upper part of the Zuberec Fm. (Kežmarok beds of Gross, 1997) near Tichý Potok village (Fig. 1). We used data from existing boreholes and geophysical logs SP and Gamma curves. Two thick outcrop sections were logged in detail (Fig. 1) and numerous smaller sections were described in order to find the lateral continuity of deposits. The logging was done in cm scale in order to recognize any subtile changes of sedimentary style. The different facies are indicated on the logs (Figs. 4 and 5) using division codes (Table 1) slightly modified after Bouma (1962) and Lowe (1982). The logs were compared to the sedimentary architecture of the area derived from photomosaics. Petrography and microstructures were studied in 13 oriented thin sections. The age of the deposits was determined by nanoplankton analyses. Ten samples prepared in laboratory of Geological Survey of Slovak Republic were studied by LM (Amplival) at a magnification of 1200x. We did detailed mapping of the area in order to find the areal distribution of the strata and to find any structures. On the basis of data obtained from the boreholes and outcrops we determined the vertical and lateral continuity of the depositional bodies and the change of depositional subenvironments.

## Results

Drill data and seismic profiles indicate the thickness of the CCP Basin fill ranging from 700 m to 3 500 m in the Levoča Mts. (Polák et al., 1994, Gíret et al., 1991, Neupauer et al., 1990, Gross et al., 1996). The thickness and lithology of deposits in the central part of the Levoča Mts. is only inferred from the seismic profiles (Gross et al., 1996). This is interpreted as transgressive deposits at the base of the sedimentary succession (Borové Fm.) overlain by thick (up to 1 000 m) shales of Huty Fm. and rhythmical flysch of Zuberec Fm. which is about 1 600 m thick (Gross et al., 1996). The Zuberec Fm. is locally missing and the whole succession is capped by predominantly sandstone of Biely Potok Fm. The thickness of the Biely Potok Fm. deposits, estimated from boreholes and outcrops, is about 700 m. Near Tichý Potok village a thickness of more than 500 m of prevailingly coarse-grained strata was measured which consists of sandstones, minor pebbly sandstones and conglomerates.

The preliminary structural study of the area showed NE - SW strike with monoclinal 5 - 15 degrees dip toward SE. The strata are displaced by a NE-SW fault system with offset ranging from a few decimeters to a few meters. The fault system has a steep dip toward NW, and does not show any indicator of movement direction. An associated joint system has E-W direction and a steep dip toward N. Some striae suggest sinistral motion. Another NW-SE fault system with a steep dip toward SW is less

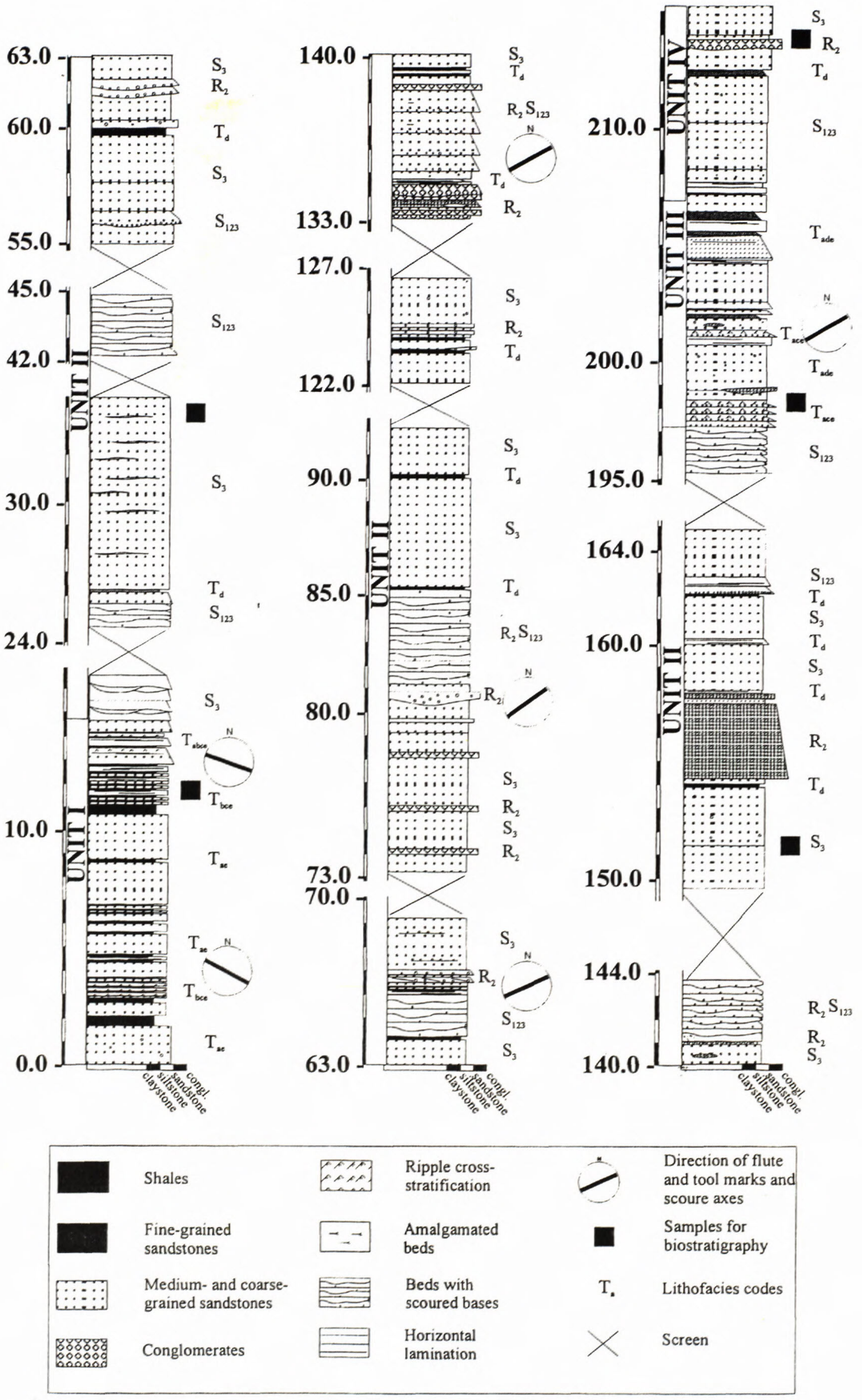



*Fig. 3: Lithostratigraphical log of the Tichý Potok I section. Note the change of the palaeotransport direction upward.*

*Fig. 4: Photograph of levee deposits at the Tichý Potok I section. Note the pinching out of the sandstone bed lying underneath the hammer.*

common. The faults locally are filled with veins of white calcite. Striae suggest two kinds of movement: the older movement represents dip-slip fault toward NW, the younger system represents a sinistral fault. The palaeostress analysis of deformation implies a maximum stress axis ($\delta_1$) in NW-SE direction and a minimum stress axis ($\delta_3$) in NE-SW direction. The palaeostress axes orientation is consistent with mineralization of the NW-SE faults system which is oriented in the direction of maximum tension stress. The structural analyses are preliminary, however, they show possible correlation of NE-SW and E-W fault systems with faults in Biely Potok Formation having the same regional character. This is supported by a Neogene age of movement on the fault systems. The measured palaeostress directions are consistent with the orientation of palaeostress axes in the Late Karpatian - Early Badenian strata of the nearby East-Slovakian Neogene Basin as described by Kováč et al. (1994). The orientation of fault systems in both Levoca Mts. and East-Slovakian Basin is also similar.

Section 1

Section 1 is located 4.5 km to the North of Tichý Potok village on the right side of Torysa river (Fig. 1). More than 210 m of strata are almost completely exposed. The sedimentary succession is divided into four lithological units, numbered from bottom to top (Fig. 3).

*Unit I*

*Description.* - Unit I extends from the base of the outcrop to 16.5 m. It consists of thick sandstone beds alternating with thin sanstone and shale beds (zebra facies, Figs. 4 and 5).

The thick sandstone beds varies from 20 cm to 1 m in thickness. The beds are aften amalgamated with a sharp and erosional base. Flute and tool marks are very common at the base of sandstones and suggest palaeocurrent direction toward northwest (Fig. 3). The sandstones are medium- and coarse-grained, massive or normally graded. Usually they represent Bouma's $T_a$ division with scarce $T_{ab}$ divisions. The sandstones are classified as medium-grained, sublithic arenites as defined by Pettijohn and others (1972). The sandstones consist of quartz, sericitic feldspars and rock fragments. Rock fragments are composed of quarzites, chloritic phylites, graphitic phylites, basic volcanics, granitoids, carbonates and muscovites. The matrix is calcite or minor clayey calcite. The grain roundness varies from 2 to 3 in the 6 degree scale of Leeder (1982). Quartz prevails in the samples and plagioclase feldspar is more common than orthoclase and microcline. Scarce conglomerates or pebbly sandstones occur at the base of the beds. The thickness of the thick sandstone bed sequence is from 50 to 200 cm.

The interbedded thin sandstone and shale bed sequence is termed as zebra facies (Nelson & Nilsen, 1997). The sandstones are fine- to medium-grained and show Bouma's $T_{ae}$, $T_{be}$ and $T_{bce}$ divisions. Starved ripples are common. Sandstone beds are 2 cm to 20 cm thick, with sharp bases. The sandstone beds are very irregular and they commonly pinch out laterally (Fig. 4). Soft-sediment deformation is very common (Fig. 5). The interbedded shales have sharp bases and the strata are about the same thickness as the sandstone beds. Shales are massive with minor parallel and ripple cross-lamination.

*Interpretation.* - The facies association suggests deposition of unit I in a submarine fan channel and levee subenvironment. The channel-fill deposits are the thick sandstone bed sequences. The sandstone locally has conglomerates or pebbly sandstones at the base. The conglomerates are associated with initial erosion in the early depositional phase of the channel deposits (Clark & Pickering, 1996). The overlying channel fill deposits mostly consist of medium-grained massive sandstone. The alternating thin sandstone and shale beds of the zebra facies are interpreted as levee deposits. They were deposited on flanks of channels where turbidity currents spilled over from the channels. This interpretation is supported by the occurrence of starved ripples, indicating a lack of sand in suspension which is typical for overbank deposits. The irregular continuity of beds which pinch out laterally as

*Fig. 5: Photograph showing sedimentary deformation in the levee deposits at the Tichý Potok I section.*

well as soft-sediment deformations are often found in levee deposits.

*Unit II*

*Description.* - Unit II extends from 16.5 m to 201.5 m. Unfortunately, lithologic details are incomplete because of cover on the outcrop, which is marked on the log (Fig. 3). Thick to very thick bedded medium-grained to granule-sized sandstones and pebble sandstones separated by discontinuous fine-grained sandstone partings or beds are characteristic of unit II (Fig. 6). The beds are often amalgamated. Individual sandstone beds are 10 - 15 m thick. The internal structure of these beds consists of 20 - 70 cm thick amalgamated sandstone beds. The sandstones and pebbly sandstones are mostly normally graded and massive. The sandstones are generally medium-grained lithic arenites. They prevailingly consist of quartz with lesser amounts of feldspars (orthoclase, sericite) and rock fragments. The rock fragments are composed of quartzites, granitoids, chloritic and graphitic phylites, serpentine, basic volcanics and carbonates. The grain roundness is 2 -3 (Leeder, 1982). Generally a matrix is absent but where present it is composed of clay. Many beds, which on visual inspection show massive structure, were found to be normally graded in oriented thin sections. The most common are $R_2$, $S_1$, $S_2$ and $S_3$ divisions of Lowe (1982), interspersed with fine-grained horizontal laminated (Bouma's $T_d$ division) sandstone partings (see Table 1 for lithofacial codes). In pebbly sandstones pebbles are either organized into discrete layers or randomly distributed. Sole marks are rare and all indicate paleocurrent direction toward southwest. Water-escape structures and soft-sediment deformation are common. The sandstone beds have either a flat sharp or scour basal contact. The scours do not erode the entire underlying bed suggesting only weak erosion. The beds vary in thickness laterally and typically cannot be correlated over wide areas because they form discontinuous lenses.

The conglomerates, consisting of quartz, sandstone, mudstone, limestone and dolomite clasts, are mostly matrix-supported. Only rarely clast-supported conglomerates occur. Massive structure prevails. At places, the conglomerates are positively graded. They fill scour surfaces or form sharp-based beds and do not make channels in the report area.

*Fig. 6: Pebbly sandstone and sandstone beds of suprafan. Note the scoured bases and normal grading.*

*Tab. 1: Lithofacies (division) codes, modified after Bouma (1962) and Lowe (1982).*

| | |
|---|---|
| $T_a$ | massive sandstone |
| $T_b$ | horizontally laminated sandstone |
| $T_c$ | ripple cross-stratified sandstone |
| $T_d$ | horizontally laminated fine sandstone and shale |
| $T_e$ | massive shale |
| $S_1$ | cross-stratified sandstone |
| $S_2$ | horizontally laminated sandstone |
| $S_3$ | massive coarse-grained sandstone |
| $R_1$ | cross-stratified conglomerate |
| $R_2$ | massive and inversely graded conglomerate |

*Interpretation.* - The sediment succession, its vertical and lateral development, the character of beds and the lack of channelization suggest deposition in a suprafan lobe subenvironment. Prevailing conglomerates, pebbly conglomerates and massive sandstone, representing $S_1$, $S_2$, $S_3$ and $R_2$ divisions of Lowe (1982), suggest deposition by high-density turbidity currents (Lowe, 1982, Walker, 1978). Most of the beds probably originated from traction and traction-carpet stage of deposition as described by Lowe (1982). The occurrence of the $T_d$ division of Bouma suggests deposition from suspension in dilute turbidite flow, probably in a subsequent sedimentation stage. The lack of matrix in some sandstones may indicate grain flow during deposition.

*Unit III*

*Description.* - The unit III deposits extends from 201.5 m to 206.8 m. Generally they are finer-grained than underlying unit II deposits. The deposits comprise beds 10 to 50 cm thick with sharp and loaded bases. The beds consist of medium-grained sandstone which is often capped by fine-grained sandstone or shale. The petrography of the sandstones does not differ from the sandstones in unit II. The sandstone intervals are composed of massive sandstones and parallel laminated and ripple cross-laminated sandstones. Wavy and convolute lamination is also common. The finer-grained deposits are laterally discontinuous and they frequently only comprise finer-grained partings in coarser grained successions. The sedimentary succession comprises $T_{abde}$, $T_{ade}$ and $T_{ace}$ divisions of Bouma.

*Interpretation.* - The occurrence of Bouma's divisions in the sedimentary succession suggests deposition by dilute turbidity flows. The weakly preserved $T_e$ divisions may have been caused by other factors like high erosive activity of turbidity flows or high frequency of turbidity flow which did not allow final suspension stage sedimentation or shortage of finer-grained fraction in the turbidity flow. The absence of channelization and the prevailing sharp bases of beds do not indicate high erosive activity of flows. We interpret these deposits as originating on the flank of a suprafan.

*Unit IV*

*Description.* - Unit IV extends from 206.8 m to 215 m. The unit has features similar to unit II. The deposits are dominately thick to very thickly bedded medium- and coarse-grained sandstones separated by fine-grained sandstone partings. The sandstone is massive and normally graded. Sandstone beds are amalgamated, the lower contacts are sharp, loaded or scoured. The petrography of sandstones is similar to the petrography of sandstones from unit II. At places, matrix-supported massive and normaly graded conglomerates and pebbly sandstone occur. Like unit II, $R_2$, $S_1$, $S_2$ , $S_3$ and sporadic fine-grained parallel laminated $T_d$ divisions are most common. The well exposed section shows relatively high lateral persistence of individual beds (over 100 m).

*Interpretation.* - The prevailingly coarse-grained deposits, normal-graded sandstones capped by parallel laminated fine-grained sandstone, pebbly sandstones, massive and normally graded sandstones and some cross-bedded clast-supported conglomerates suggest deposition by high-density turbidity flows. This interpretation is supported by sediment succession throughout the section. We believe that deposits of unit IV have originated in a deep-marine suprafan subenvironment.

Section 2

Section 2 is located NW from the village Tichý Potok on the right side of Torysa river near a former quarry (Fig. 1). It lies 500 m to the west of section 1. The exposed section is 20 m high and 50 m wide. The strata in the section were divided into two units (Fig. 7).

*Unit I*

*Description.* - Unit I extends from the base of the outcrop to 11.8 m. It consists of thick sandstone beds and thin, alternating sandstone and shale beds resembling zebra the facies.

The thick sandstone beds have sharp bases and at places the bases show flute and tool marks. The flute marks suggest palaeoflow toward northwest. The thickness of individual beds is about 30 cm with a maximum thickness of 100 cm. The thickness of bed complexes is about 2 m. The sandstone is medium- and coarse-grained, massive and horizontally laminated. Normal grading occurs infrequently. Some of the beds contain pebbly sandstone at the base.

Thin beds of alternating sandstones and shales form 2 m thick sequences between the thick sandstones. The beds are 5 - 10 cm thick, have a sharp base, are laterally non-persistent and are generally deformed. The sandstone is medium grained but some is fine-grained. Usually it is massive, parallel laminated and ripple cross-laminated. Starved ripples are common. Shales are massive or parallel laminated. The deposits comprise $T_{ace}$ and $T_{ce}$ divisions of Bouma.

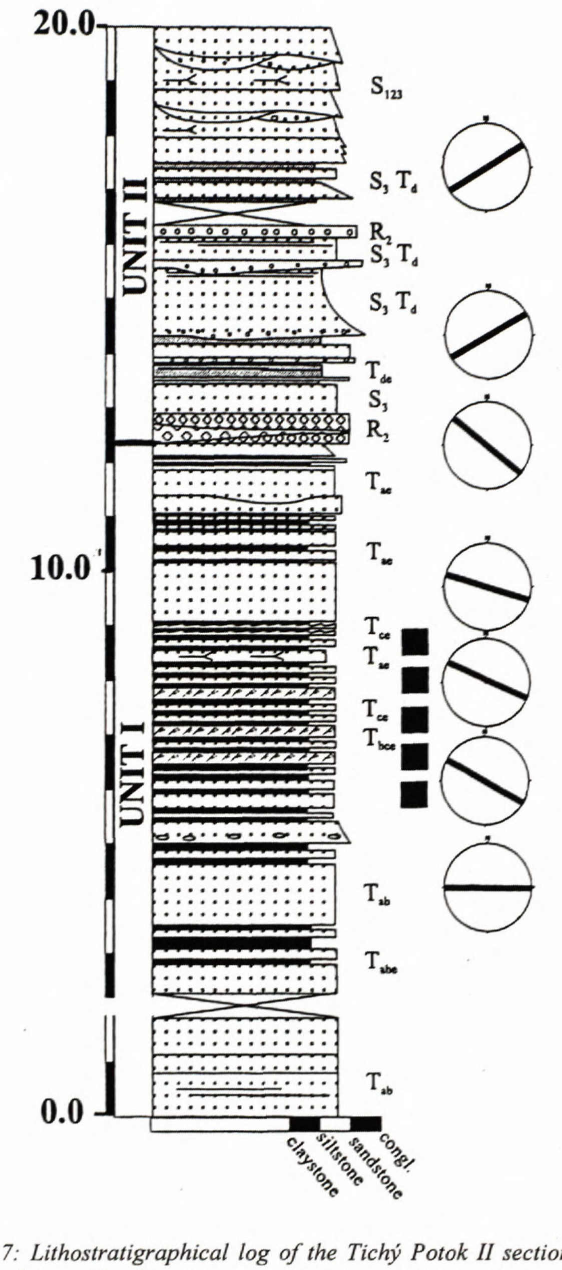



*Fig. 7: Lithostratigraphical log of the Tichý Potok II section. Legend as on Fig. 3.*

*Interpretation.* - The described sedimentary succession is thought to represent channel-and-levee deposits of a submarine fan. Thick-bedded sandstones comprise channel fill facies which laterally pass into alternating thin beds of finer sandstone and shale representing levees. The levee interpretation is supported by the occurrence of starved ripples suggesting lack of sand in suspension. The lenticular beds and soft-sediment deformations are also typically developed on levee slopes.

*Unit II*

*Description.*- Unit II extends from 11.8 m to the top of the section at 20 m. Unit II consists of thick sandstone and minor pebbly sandstone and conglomerate beds. The base of beds is sharp, scoured and loaded. The beds are from 20 cm to 100 cm thick and generally are amalgamated. Sandstone is medium- to coarse grained. Sandstone beds are massive and normally graded. The top of beds are commonly faintly parallel laminated comprising Bouma's divisions $T_{ab}$. Pebbly sandstone and matrix-supported conglomerate occur either at the base of sandstone beds or in fills of small scours. The thickness of deposits in scours is not more than 30 cm.

*Interpretation.* - The strata are mostly massive and normally graded sandstones with sharp bases and infrequent load and scour surfaces suggesting deposition by high-density turbidity currents. Some of the massive sandstones may have been deposited by grain flow. The absence of finer deposits ($T_e$ divisions) probably indicates high sediment input into the basin, insufficient time for suspension sedimentation and high erosive flow capability. The lack of channelization together with the occurrence of coarse deposits suggest deposition in a submarine suprafan.

**Borehole descriptions**

Sedimentologic studies from the measured sections were supplemented by data obtained from a series of 50 - 100 m deep hydrogeologic boreholes which were recently drilled near Tichý Potok village (Gíret et al., 1991, Neupauer et al., 1990). The boreholes drilled northwest from Tichý Potok revealed: 1) up to 25 m of thick sandstone, pebbly sandstone and conglomerate; 2) up to 5 m of thick sandstone, pebbly sandstone and conglomerate consisting of thick beds; 3) interbedded thin bedded sandstones and shales (Gíret et al. 1991, Fig. 8). Athough we did not examine samples from the boreholes, the available descriptions imply an origin in the suprafan subenvironment (up to 25 m thick sandstone complexes), and an origin in a channel-and-levee subenvironment (up to 5 m thick sandstone complexes and complexes consisting of alternating thin beds of sandstones and shales).

**Biostratigraphy**

Ten samples were taken from section I and II for nanoplankton analyses. Five samples are from the channel-and-levee deposits, five samples are from suprafan deposits (see marks on logs, Figs. 3 and 7). The samples from channel-and-levee deposits contained nannoplankton of NP 25 / NN1 zones. This suggests Late Oligocene - Early Miocene (Egerian) age for the channel-and-levee deposits. All samples from the suprafan deposits showed only rare reworked Cretaceous and Eocene nanofossils or were barren. This probably reflects very intensive sedimentation rates from high-density flows which were poor conditions for planktonic life. The following assemblages were found in the samples:

Sample 1/97: *Cyclicargolithus floridanus, Helicosphaera euphratis, Coccolithus pelagicus Helicosphaera* sp. - Late Eocene - Oligocene

Sample 2/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Cyclicarglithus abisectus, Dictyococcites lockerii, Sphenolithus moriformis, Helicosphaera* cf. *scissura, Triquetror-*

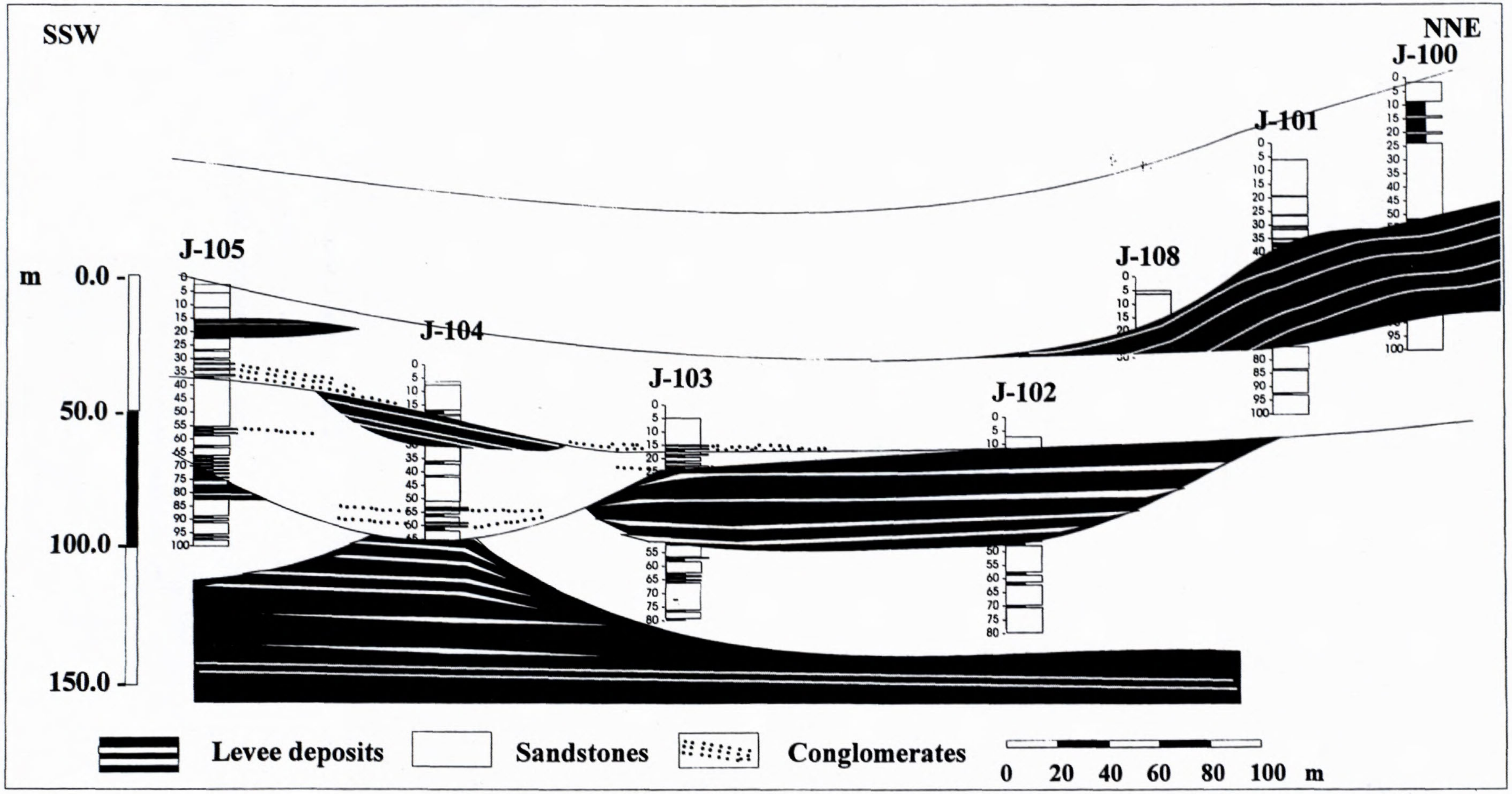



*Fig. 8: Cross-section showing sediments recovered by drillings and geological interpretation of studied deposits. For location of the section see Fig. 1.*

*habdulus* cf. *carinatus* + rare reworked Cretaceous forms - poor assemblage of Late Oligocene - Early Miocene NP 25/NN1 (Egerian)

Sample 3/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Dictyococcites lockerii, Helicosphaera scissura* + rarely Cretaceous redepositions - very poor assemblage of Late Oligocene - Early Miocene NP 25/NN1 (Egerian)

Sample 4/97: *Cyclicargolithus floridanus, Dictyococcites bisectus, Helicosphaera euphratis, Dictyococcites lockerii, Reticulofenestra umbilicus, Helicosphaera* cf. *scissura, Triquetrorhabdulus carinatus* + rarely reworked Cretaceous forms, poor assemblage probably of Late Oligocene - Early Miocene age NN1

Sample 5/97: *Cyclicargolithus floridanus, Coccolithus pelagicus, Coccolithus formosus, Dictyococcites bisectus, Cyclicargolithus abisectus, Triquetrorhabdulus carinatus, Helicosphaera euphratis, Helicosphaera scissura* + rare reworked Cretaceous forms, poor assemblage of Late Oligocene - Early Miocene age NN1

The markers (*Cyclicargolithus abisectus, Triquetrorhabdulus carinatus, Helicosphaera scissura*) point to the Late Oligocene/ Early Miocene (Egerian) age of the strata under study. This is in accordance with the older studies by B. Hamršmíd on the material from Tichý Potok village supplied by J. Soták (Slovak Academy of Science) and also with the results by A. Nagymarosy (Eötvös Univ., Budapest) (Soták, pers. commun.).

## Discussion

The sedimentary succession at the measured sections and in the boreholes consists of channel-and-levee deposits and suprafan deposits. The association of channel-and-levee facies suggests either the existence of depositional and erosional channels (Normark, 1970) or aggradational channels (Clark & Pickering, 1996). The aggradational channels channels are associated with large terrestrial drainage areas Kenyon, 1992), high channel sinuosity, lower slopes and finer-grained sediments that aid suspension in turbidity currents (Clark & Pickering, 1996). The correlation of borehole cores shows sandstone bodies progressively merging toward the top of the section (Figs. 8 and 9). This may be a result of multilateral channel coalescing causing connection of individual channel-fill deposits or, more likely, it reflects alternation of channel-and-levee and suprafan deposits (see below). The width of the channels in the lower part of the section is estimated to vary from 200 m to 2 km. Depth of the channels ranges from 20 to 40 m. The thickness of levee complexes is variable. The borehole profiles suggest a thickness of up to 40 m, the thickness of deposits observed in outcrops does not exceed 12 m. A greater thickness of levee deposits is usually expected downfan because larger amounts of coarser material can be transported across the channel margins where the channels are shallower (Nelson & Nilsen, 1997). The stratigraphic arrangement suggests a progradational submarine fan system where the thickness of

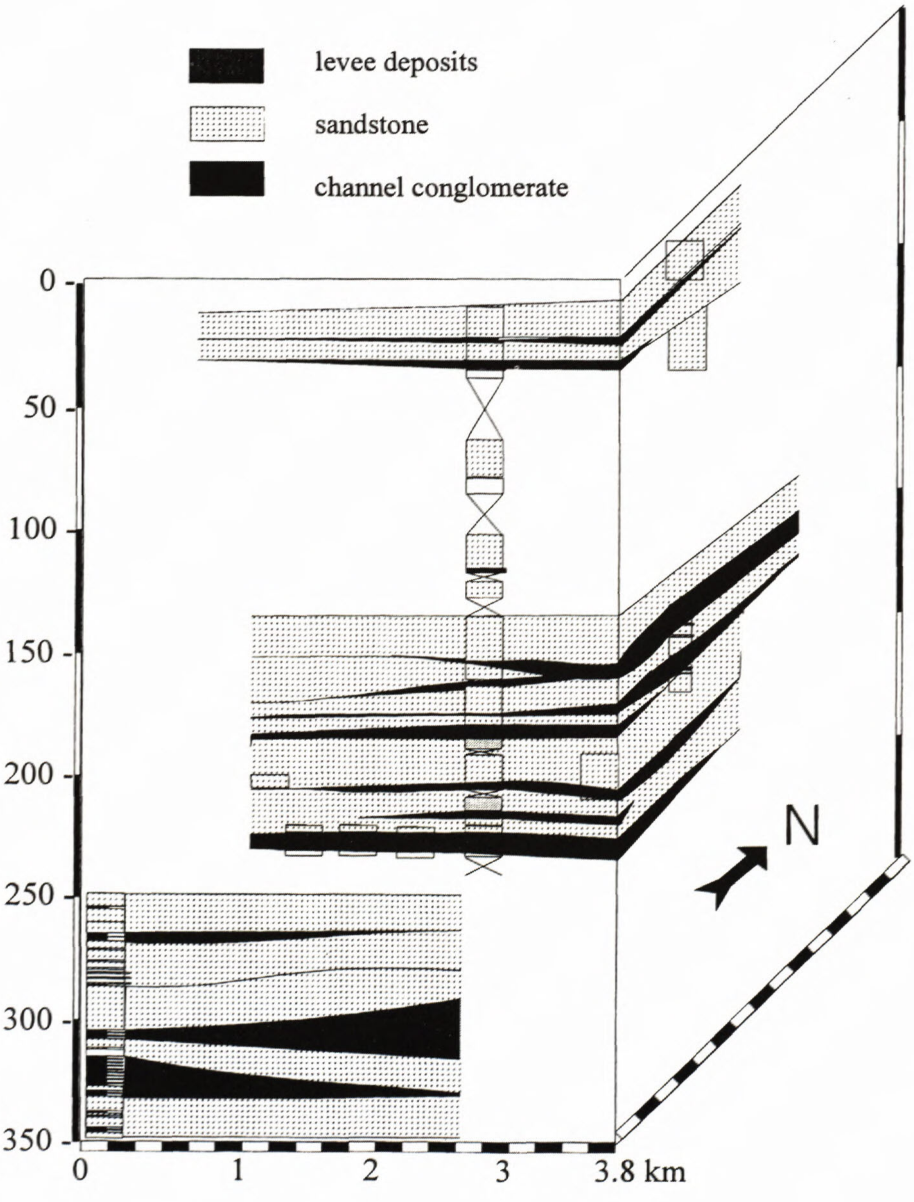



*Fig. 9: Blockdiagram showing vertical and lateral relationship of channel-and-levee and suprafan deposits. Note the alternation of lower and higher interconnectivity of sandstone bodies.*

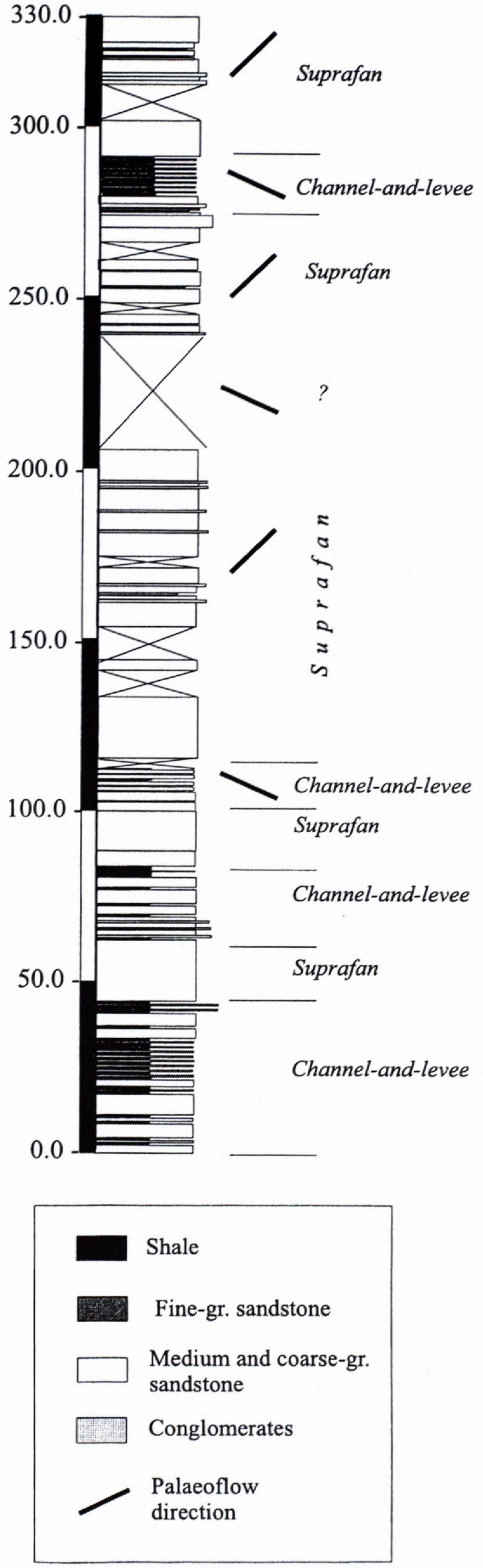



*Fig. 10: Composite log showing the sedimentary succession in the Tichý Potok area. For the construction the data from the borehole J-105 and sections Tichý Potok I and II were used.*

levee complexes decreases upward with a gradual shift of depositional system toward the basin depocenter.

The suprafan deposits indicate a change of depositional style resulting from high-density unchannelized gravity (mostly turbidity) flows. This kind of deposition is typical for areas with intensive uplift of basin margins (source areas) and a narrow shelf. It is often described from tectonically-controlled basins where abrupt uplift/subsidence events result in formation of turbidity aprons (Chan & Dot, 1983, Reading & Richards, 1985, Stow, 1985). The formation of such aprons originated by flows entering the basin perpendicular to the basin axis would be consistent with the palaeoflow indications found in the channel-and-levee deposits and in the suprafan deposits. The change of the palaeoflow direction from the SE - NW in the channel-and-levee deposits to the NE - SW in the suprafan deposits suggests a palaeoflow pattern perpendicular to the basin axis in some phases of the basin development.

The correlation of deposits between the two measured sections and boreholes shows an alternation of channel-and-fill deposits and suprafan deposits (Figs. 8 and 9). The alternation may have been caused by other factors such as basinward or lateral shift of the suprafan, change in sediment input or tectonics. It can explain the gradual merging of sandstone bodies upward in the borehole because the lower part of the section is formed by channel-and-levee deposits and the upper part by suprafan deposits. The alternation of channel-and-fill and suprafan deposits may have implication for the interpretation of basin stratigraphy. The deposits resembling channel-and-fill deposits from the measured sections were described as Kežmarok beds (member) which are the uppermost part of the Zuberec Formation (Gross, 1997). However, at the studied localities these deposits are overlain by 160 m of strata typical of the Biely Potok Formation, which are, in turn, overlain by channel-and-levee deposits, possibly the Kežmarok beds (Fig. 10). According to this correlation the Kežmarok beds (channel-and-levee deposits) should be a part of Biely Potok Formation. The correlation of these deposits also suggests the Late Oligocene - Early Miocene age (NP 25 / NN 1) for all investigated deposits.

## Conclusion

The deposits at the measured sections located near Tichý Potok village in the eastern part of the CCP Basin (Fig. 1) are composed of gravity (mostly turbidity) flow deposits of Late Oligocene and Early Miocene age (nanoplankton zones NP 24/25 and NN 1). The deposits were laid down in suprafan and channel-and-levee subenvironments of a submarine fan. Suprafan deposits consist of thick sandstone bodies with minor pebble sandstones, conglomerates and shale partings. The sandstones, which may be up to 50 m thick, are composed of thick amalgamated beds with sharp and scoured bases. The prevailing normal grading, the presence of $R_2$, $S_{1,2,3}$ divisions of Lowe and the $T_d$ division of Bouma strongly suggest turbidity flows as the main agent responsible for their deposition. Channel-and-levee deposits consist of thick-bedded sandstones, some pebble sandstones and conglomerates (channel fill) and alternation of thin-bedded sandstones and shales (zebra facies).

The composite log of deposits in the studied area (Fig. 10) shows alternation of suprafan and channel-and-levee deposits. The alternation suggests possible assignment to the Biely Potok Formation of the channel-and-levee deposits described as the Kežmarok beds by Gross, 1997. However, the assignment requires further, more detailed investigation.

*Acknowledgement*

The work was financially supported by Norsk Hydro, a.s., Norway and the Ministry of Environment, Slovakia. The analytical part of the work was carried out at laboratories of the Geological Survey of Slovak Republic. P. Gross read the manuscript and made useful suggestions. He is also thanked for introducing us to the geology of the CCP Basin. R.B. O Sullivan corrected the English language.

## References

Biely A., Bezák, V., Elečko, M., Kaličiak, M., Konečný, V., Lexa, J., Mello, J., Nemčok, J., Potfaj, M., Rakús, M., Vass, D., Vozár, J. & Vozárová A., 1996: Geologická mapa Slovenskej republiky. Ed. by Geological Survey of Slovak Republic.

Bouma A. H., 1962: Sedimentology of some flysch deposits. Amsterdam, *Elsevier*, 168 pp.

Chan M.A. & Dott R. H. Jr., 1983: Shelf and Deep-Sea Sedimentation in Eocene Forerc Basin, Western Oregon - Fan or Non-Fan? American Association of Petroleum Geologists, *Bulletin* 67, 11, 2100 - 2116.

Clark J. D. & Pickering K. T., 1996: Architectural Elements and Growth Patterns of Submarine Channels: Application to Hydrocarbon Exploration. AAPG *Bulletin* 80/2, 194-221.

Csontos L., Nagymarosy A., Horvath F. & Kováč M., 1992: Tertiary evolution of the Intra-Carpathian area: a model. *Tectonophysics*, 208, 221-241.

Francü J. & Müller P., 1983: Organic matter maturity i Perri-Klippen Flysch of the Inner carpathian Mountains (East Slovakia). *Geol. Carpathica* 36, 483-494.

Giret A., 1991: VN Tichý Potok - predbežný prieskum. Manuscript, Geoconzult Košice.

Gross P., Köhler E. & Samuel O., 1984: Nové litostratigrafické členenie vnútrokarpatského paleogénu. *Geologické práce, Správy* 81, 103-117.

Gross P., Buček S., Borza V., Ďurkovič T., Filo I., Halouzka R., Janočko J., Karoli S., Kováčik M., Lukáčik E., Maglay J., Mello J., Nagy A., Polák M., Spišák Z., Vozár J., Žec B., Jetel J., Raková J., Samuel O., Siráňová Z., Túnyi I., Zlínska A., Žecová K. & Snopková P. 1996: Vysvetlivky ku geologickej mape Popradskej kotliny, Hornádskej kotliny, Levočských vrchov a šarišského paleogénu. Manuscript, Geological Survey of Slovak Republic, Bratislava.

Gross P., 1997: Kežmarské vrstvy - nový člen paleogénu podtatranskej skupiny. *Geologicke Práce, Správy* 103.

Janku J., Nemec T., Koráb T. & Rudinec R., 1987: Výsledky výskumných prác na prírodné uhľovodíky na území SSR a vyhľadavácieho prieskumu v predneogénnych útvaroch na východnom Slovensku v r. 1978-1986. Knihovníčka Zemního Plynu a Nafty, 7, 63-75.

Janočko J., 1996: Relationship between longitudinal turbidite fans and lateral turbidite aprons: fill facies architecture of a narrow, tectonically-controlled basin. Research Project Proposal, Geological Survey of Slovak Republic.

Janočko J., 1997: Zostavenie Geologickej mapy 1:50 000 a vysvetliviek Spišskej Magury. Projekt, manuscript, Geological Survey of Slovak Republic.

Kenyon N. H., 1992: Channelized deep-sea siliciclastic systems: a plan veiw perspective: Sequence Stratigraphy of European Basins. CNRS/Institute Francais du Petrol, 458-459.

Koráb T., Ďurkovič T., Kullmanová A., Martinsky L., Miko O., Gašparíková V., Snopková P., Harca V., Francû J., Zembiak O., Michalíček M., Procházková V., Rudinec, R., Řeřicha, M., Smetana, J., Jandová, R., Pichová, E., Plička, M., Hradil F., Filková V., Wunder D., Husák P. & Karkoška, F. 1986: Výskum vnútrokarpatského paleogénu a jeho podložia v Šarišskej vrchovine a v Levočskom pohori. Záverečné naftovo-geologické zhodnotenie oblasti na základe vrtu Šariš-1. Manuscript, GSSR Bratislava.

Kováč M., Vass D., Janočko J., Karoli S. & Kaličiak M., 1994: Tectonic History of the East Slovakian Basin During the Neogene. *Slovakian Geology:* Korab Memorial Volume, Bratislava, 1-15.

Kuenen P. H. & Magliorini C. I., 1950: Turbidity currents as a cause of graded bedding. *Journal of Geology* 58, 91-127.

Leeder M. R., 1982: Sedimentology: process and product. London, George Allen and Unwin, 344 pp.

Leško B., Chmelík F. & Rudinec R., 1982: Perspektívne územie na ropu a zemný plyn východne od Nízkych Tatier. *Geologický Průzkum*, 24, 37-39.

Leško B., Ďurkovič T., Franko O., Gašparíková V., Harca V., Nemčok J., Kullmanová A., Jandová V., Kristek J., Vaňová M., Šterba L., Rudinec R., Smetana J., Suppina Z., Wunder D., Kudera L. & Faber P., 1983: Oporný vrt Lipany - 1 (4 000 m). *Regionálna Geológia Západných Karpát*, 18, 1-78.

Lowe D. R., 1982: Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. *Jour. Sed. Petrol.*, 52/1, 0279-0297.

Marschalko R., 1964: Sedimentary structures and palaeocurrents in the marginal lithofacies of the Central-Carpathian Flysch. Develop. in Sedimentology, 3. In Bouma, A. H. and Brouwer, A. (eds.): *Turbidites*, Amsterdam, 106-126.

Marschalko R., 1966: Geológia a sedimentológia flyšových okrajových litofácií centrálnych Karpát (Šarišská vrchovina). *Zbor. Geol. Vied Západné Karpaty* 5, 1-102.

Marschalko R., 1968: Facies distribution, paleocurrents and paleotectonics of the Paleogene flysch of Central West Carpathians. *Geol. Zbor. Geol. Carpathica*, XIX, 1, 69-94.

Marschalko R., 1970: Deep submarine erosion in turbidites sequences (Central Carpathian Flych, Levocske Pohorie Mts.). *Geol. Zbor. Geologica Carpathica*, XXI, 1, 167-174.

Marschalko R., 1978: Vývoj sedimentárnych bazénov a paleotektonické rekonštrukcie Západných Karpát. In: Paleogeografický vývoj Západnych Karpát. Konferencie, sympózia, semináre. Bratislava, 49-80.

Marschalko R., 1982: Podmorské náplavové kužele v paleogéne centrálnych Karpát a rozšírenie flyša pod neogénom východného Slovenska. In: Zborník Slávikove dni október 1980, Košice - Bratislava, 47-64.

Mutti E., 1985: Turbidite systems and their relations to depositional sequences. In: Zuffa G. G.,(Ed.): Provenance of Arenites, 65 - 93.

Mutti E. & Ricchi Lucchi F., 1972: Le torbiditi dell'Apennino setterntrionale: introduzioone all'analisi di facies. Memorie della Societa Geoloiga Italiana, 11, 161-199. English Translation by T.H. Nilsen, 1978, *International Geology Review* 20, 125-166.

Nelson C. H. & Nilsen T. H., 1997: Modern and ancient deep-sea fan sedimentation. Lecture Notes for SEPM Short Course No. 14. SEPM, Tulsa, Oklahoma.

Neupauer L., 1990: Levočské vrchy. Záverečná správa z vyhľadávacieho hydrogeologického prieskumu. Manuscript, Geoconzult Košice.

Normark W. R., 1970: Growth patterns of deep-sea fans. AAPG *Bulletin* 54, 2170-2195.

Pettijohn F. J., Potter P. E. & Siever R., 1987: Sand and sandstone. New York, Springer-Verlag, 618 pp.

Polák M., Gross P., Samuel O., Snopková P. & Vozárova A., 1992: Litologické a petrografické vyhodnotenie vzoriek z hydrogeo-

logických vrtov SAL 1-7 a BS 1-5. Manuscript, Geological Survey of Slovak Republic.
Reading H. G. & Richards M.,1985: Turbidite Systems in Deep-Water Basin Margins Classified by Grain Size and Feeder System. American Association of Petroleum Geologists, *Bulletin* 78, 5, 792-822.
Rudinec R., Řeřicha M., Smetana J. & Stankovská A., 1988: Záverečná správa o vyhľadávacom prieskume na živice - vnútorný flyš - vyhľadávací prieskum na štruktúre Lipany. Vrty Lipany - 2, 3, 4, 5. Manuscript, Geofond Bratislava.
Rudinec R., Smetana J. & Stankovská A., 1989: Záverečná správa o vyhľadávacom prieskume na živice - vnútorný flyš - vyhľadávací prieskum na štruktúre Plavnica. Vrty Plavnica - 1, 2. Manuscript, Geofond Bratislava.
Soták J., Bebej J. & Biroň A., 1996: Detrital Analysis of the Paleogene flysch deposits of the Levoča Mts.: evidence for sources and paleogeography. *Slovak Geol. Mag. 3-4*, 345-349.
Stow D. A. V., 1985: Brea oilfield turbidite system, North Sea. In: Bouma, A. H., Normark, W.R. & Barnes, N.E. 1985 (Eds.): Submarine fans and related turbidite systems. New York, Springer Verlag, 231-236.
Vail P R., Mitchum R. M. Jr. & Thompson S. III, 1977: Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level. American Association of Petroleum Geologists, *Memoir* 26, 83-97.
Walker R. G., 1978: Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. Amer. Association of Petroleum Geologists, *Bulletin* 62, 932-966.

*Slovak Geol. Mag. 4, 1(1998), 17–28*

# New morphostructural division of Slovakia

JÁN LACIKA and JÁN URBÁNEK

Institute of Geography of Slovak Academy of Sciences, Štefánikova 49, 841 07 Bratislava

***Abstract.*** This contribution offers a new morphostructural division of the Slovak Republic area accepting new geomorphological and geological facts. It is different to the older Mazúr's division (1979 and 1980) and the geological regionalisation made by Vass et al. (1988). The morphostructural units have been divided according to tectonical movement tendency, relation to the neighbouring units and inner morphostructural dissection.

The Slovak Republic area are divided into following morphostructures:

*A. Carpathians:* 1. West Carpathians, 1.1 Central morphostructures of the West Carpathian dome, 1.2 Transitive morphostructures of the West Carpathian dome, 1.3 Marginal morphostructures of the West Carpathian dome, 1.4 Southern depressed morphostructures, 1.5 Southern elevational morphostructures, 2. East Carpathians: 2.1 Outer zone morphostructures of the East Carpathians, 2.2 Inner zone morphostructures of the East Carpathians;

*B. Pannonian Basin:* 1. West Pannonian Basin, 1.1 Záhorie morphostructures of the Pannonian Basin, 1.2 Danube morphostructures of the Pannonian Basin; 2. East Pannonian Basin: 2.1 East Slovakian morphostructures of the Pannonian Basin.

The West Carpathians is a megamorphostructure which has acquired a form of a large dome. This dome has an ecliptical ground plane and an asymetrical shape. Its centre is situated to NE. There are six mountains and two intramontane basins in the centre. They are Central morphostructures of the West Carpathians. The most extensive are Transitive morphostructures of the West Carpathians between centre and margin of the West Carpathians dome. They are very various from geological and geomorphological point of view. It consists more or less dissected horsts and grabens. The Marginal morphostructures of the West Carpathians border on the Panonian Basin or the South morphostructural depression. The West Carpathian dome is limited by the South morphostructural elevation in the South.

The East Carpathians has a zonal composition. There are Outher zone morphostructures in the North and Inner morphostructures in the South.

The Pannonian Basin is divided into the West and East Pannonian Basin. This morphostructures have developed as large subsided blocks.

***Key words:*** morphostructure, morphotectonics, Carpathians, Slovakia

## Introduction

The Slovak geomorphologists used the morphostructural regionalisation of Slovakia worked out by Emil Mazúr for about three decades. The first of his two modifications was presented in a form of a scientific article (Mazúr, 1979), the second was included in several geomorphologic maps in the Atlas of the SSR, the chapter IV - Povrch (Mazúr - Jakál, eds.,1980). This contribution is an attempt to create a new morphostructural regionalisation of the Slovakia ´s territory, with an ambition to finalise the conceptual plan only indicated in Mazúrs's work and at the same time to include new geomorphologic and geological knowledge unknown three decades ago.

## Methods and terminology

This work applied a multilevel morphostructure regionalisation with accepted principles of individual and typological regionalisation. It prefers individual regionalisation on the high levels, the lower levels have a character of typology.

Morphostructure is a key term of this contribution. It has been introduced to the literature by a prominent Russian geomorphologist Gerasimov in 1946. He defined it as an relief element which rises in the consequence of the historically developing mutual activities of the endogenous and exogenous processes with dominance of the endogenous factor. This term spread to the Central and Eastern Europe (including Slovakia) of former Soviet Union, while the western geomorphologists prefer an equivalent term the morphotectonic unit. Mazúr (in: Mazúr - Jakál, eds., 1980) defined morphostructure as a geomorphologic form, basic shapes and structural individualisation of which are generated by the direct active (mobile) tectonics. Some scientists accepted a wider conception of morphostructure as a land form affected by the properties of the passive (static) component of the geological structure. The land forms created by an active component of the geological structure are regarded as active morphostructures (for instance uplifted horsts). The passive components of a geological structure take part in creation of the passive morphostructures (for instance an erosionally destroyed volcano).

### Mazúr´s morphostructural regionalisation

The presented individual morphostructural regionalisation (Fig. 3) corresponds to the Mazúr´s division of the Slovakia's territory (Fig. 1) on the highest hierarchical level only. The first level discerns the Carpathians and the Pannonian Basin within Slovakia and the second level dissects the Carpathians to the Western Carpathians and Eastern Carpathians. This morphostructural regionalisation uses different criterion from that of Mazúr´s on the lower levels, therefore there is an absence of the more expressive intersection between the selected morphostructural units.

The passive structure (folded, flysch, klippen and volcanic etc.) occurred as too vulnerable forms which does not correspond to their present task in the relief forming act. The present morphostructures are developing more in the direction of the active (fault) structures, which causes gradual and irreversible destruction of the passive structure. The task of the passive structure in present morphogenesis of the Slovakia's territory consists entirely of the regulation of the selective erosion and denudation. Therefore the utilisation of the passive structure attributes as classification criterion was reduced at high level of the regionalisation and emphasised or kept at lower levels.

We hold on using of regional terminology of the divided individual units unlike the Mazúr´s morphostructural division (to observe the principle of not confusing the components of the individual and typological regions at the same level. The individual morphostructural units used by this regionalisation of the Slovakian territory are delimited to the level of units (celok - in Slovak) and less frequently to subunits (podcelok - in Slovak) and they have their own names (for instance. morphostructure of the Malé Karpaty Mts., morphostructure of the Žiarska kotlina Basin etc.). They are morphostructures of the fifth hierarchical level.

### Comparison of the morphostructural and geological regionalisations

The geological and morphostructural maps project the same thing. It is the geological structure. In spite of it there is only little agreement as far as the contents is concerned. The cause are the different geological and geomorphologic views of the matter. The interest of an geologists is considerably wider in the vertical and temporal dimensions. They study the geological structure starting by the surface and ending by the positions under the earth mantle, on the other hand geomorphologists limit their research only to the superficial or shallow underground Earth sections which take part in relief modelling. Old structural units are often presented by the geological maps, the development of which was finished, i.e. they are passive at the present time. Morphostructural maps are focused on considerably younger structural active units, the development of which is yet incomplete.

Little agreement of the comparable hierarchy regions in the map of the morphostructures (Fig. 3) and the map which interpretes the geology of the regional units of the Slovakia"s territory (Fig. 2) is obvious. The geological map (Vass et al., 1988) does not define the high hierarchy regional units, for instance the Carpathians, the Pannonian Basin, the Eastern Carpathians, etc. The highest unit was the region (oblasť - in Slovak) or zone (pásmo - in Slovak) in the four level regionalisation (for instance, Jadrové pohoria area, Gemerské pásmo zone). The units between the 3rd and the 4th hierarchy in new morphostructural map (lower than for instance Central morphostructure of the West Carpathian dome and higher than for instance the Tatra central morphostructure in Fig. 3) are roughly comparable to the highest hierarchy of the geological units in Fig 2.

The first of the comparing maps (Fig. 3) illustrates the result of the relief-forming process in the youngest phase of development, named by the geomorphologists the neotectonical phase as it depicts the active morphostructures of block-like type. Exogenous geomorphologic processes selected by differentiated tectonic block movements influenced destructively the structural units shown on the second map (Fig 2). They change the quality of the passive structures, for instance the klippen zone or the neovolcanic compounds. Comparison of figs 2 and 3 shows that geological and morphostructure frontiers agree only at the interface between the Carpathians and the Pannonian Basin. The boundaries of the majority of the intracarpathian basins is similar in both maps. The older the geological units, the lower similarity to morphostructures.

### The basic characteristics of morphostructures

### 1. The Carpathians

The Slovak Carpathians are represented by the western part of a massive of the Carpathians arch, which is a part of the Alpine-Himalayan system. The Slovak Carpathians belong to the West Carpathians, except its easternmost area, which is a part of the East Carpathians.

### 1.1 The West Carpathians

The overall shape of the West Carpathians is that of a large dome. Its ground-plan is close to ellipse (Mazúr, 1979). The top of the dome is not precisely centred. It is shifted towards its north-eastern border. This megamorphostructure inclines from its asymmetrically situated centre to its circumferential and peripheral parts towards the lowland area of the Pannonian Basin on the south-west and south-east and towards the longitudinal Juhoslovenská depression in the south. This depression is limited in the opposite side by the elevation zone of Matra morphostructure.

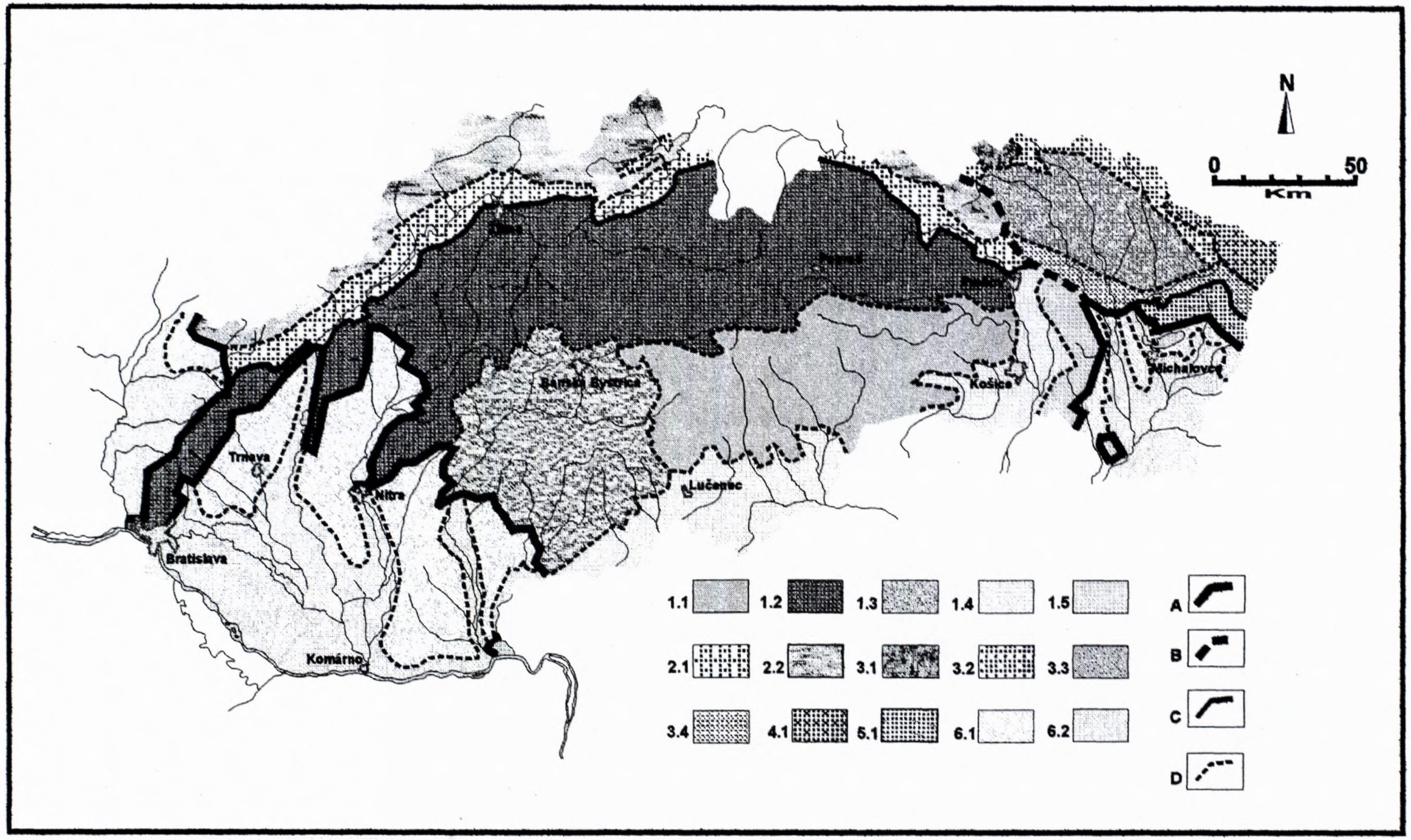



*Fig. 1 Morphostructural division of Slovakia according to Mazúr (1980).*

*1. Morphostructures of the Inner West Carpathians; 1.1 Semi-massive morphostructure of the Slovenské Rudohorie Mts., 1.2 Folded-block Fatra - Tatra morphostructure, 1.3 volcanic block structure of the Slovenské Stredohorie Mts. 1.4 Lučenec - Košice depression, 1.5 Matra - Slaná block morphostructure; 2. Morphostructures of the Outer West Carpathians, 2.1 morphostructural depression of the peri-pieniny (Klippen) lineament, 2.2 fault-folded structures of the flysch Carpathians, 3. Morphostructures of the transitional zone - transversal depression of the Nízke Beskydy Mts., 3.1 partial positive morphostructures, 3.2 transitional morphostructures: uplands, 3.3 transversal depression proper - hilly land, 3.4 structure of the peri-Pieniny lineament, 4. Morphostructures of the Outher West Carpathians, 4.1 block-folded positive morphostructure of the flysh zone, 5. Morphostructure of the Inner East Carpathians, 5.1 block Vihorlat-Gutín structure, 6. Morphostructure of the Pannonian Basin, 6.1 sightly elevated morphostructures within the Pannonian depression,6.2 recent susiding morphostructures with aggradation; Morphostructural boundaries: A. Carpathians-Pannonian Basin boundary; B. West and East Carpathian boundary; C. Inner and Outer Carpathian boundary; D. morphostructural regions boundary*

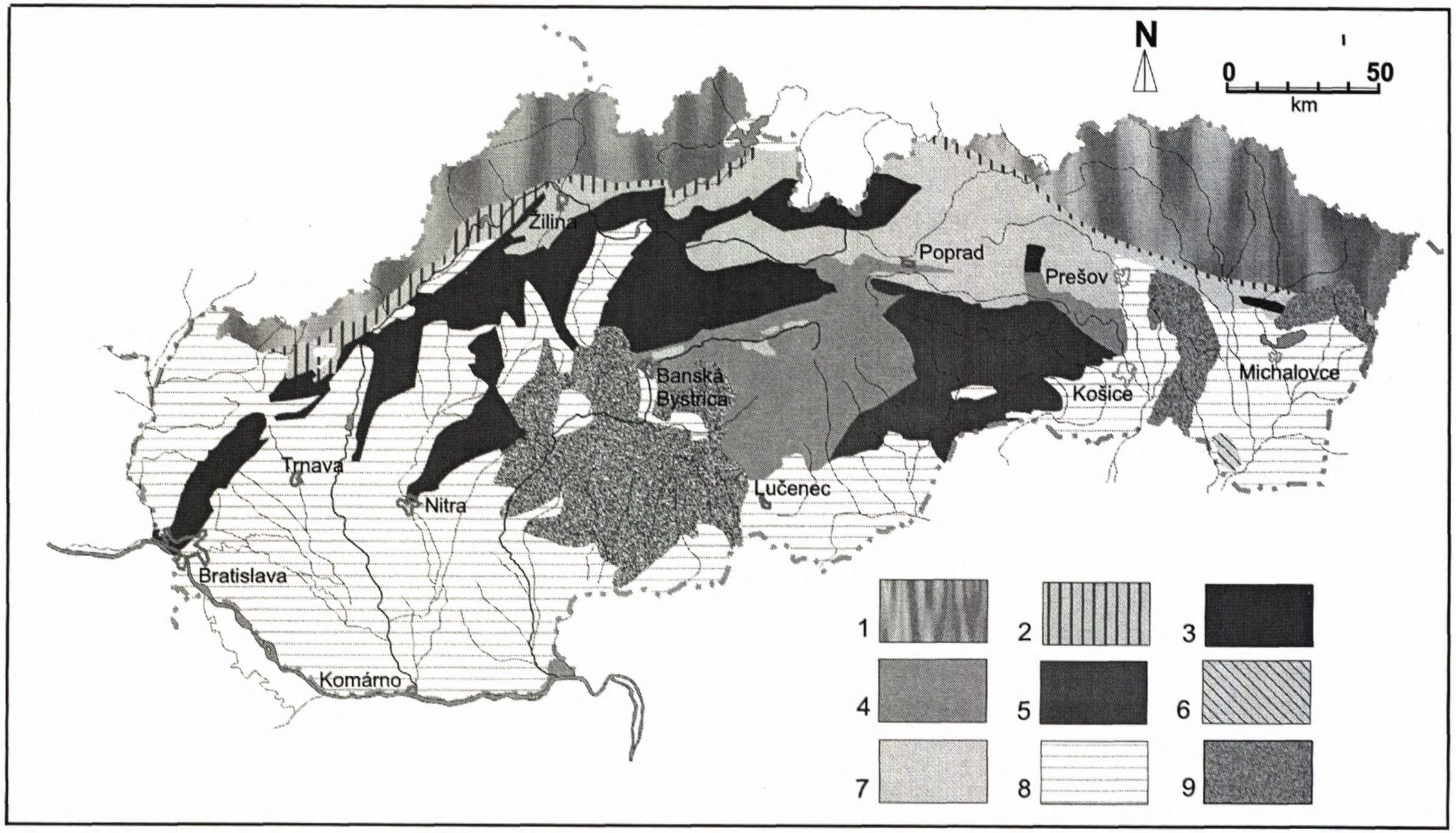



*Fig. 2 Regional geological division of the West Carpathians and northern protuberances of the Pannonian Basin in the territory of Slovakia according to Vass et al. (1988)*
*1. Flysh zone, 2 Klippen zone and sub-klippen areas, 3. Core mountains, 4. Veporik zone, 5. Gemeride zone,. Zemplínske vrchy Mts., 7. Inner Carpathian Paleogene, 8. Inner Carpathian basins, 9. Neovolcanic areas*

### 1.1.1 The central morphostructures of the West Carpathian dome

The central morphostructures represent the most uplifted part of the West Carpathians and whole Carpathian arch. Their mountains reach the highest altitude and also their basins are in the highest position in Slovakia. This unit is at the same time the most internally differentiated and the most contrasting one. The differences between mountains and basins in central part of the dome reach the highest values (max. almost 2 000 m). Two units of the 4th hierarchy level are distinguished within the central morphostructure.

*a) The Tatra central morphostructure*

The main geomorphologic axes of the morphostructure situated east of the dome centre are running in the west-eastern direction. It is the highest morphostructure in Slovakia, surpassing the altitude of 2 000 metres. There are two expressive elevations: *the Vysoké Tatry Mts.* and *the Nízke Tatry Mts.* bordered by a relatively subsided longitudinal depression *the Podtatranská kotlina basin.* Its eastern part (the Popradská kotlina basin) is almost by 2 000 metres lower than the Tatra mts. Also less uplifted submontane morphostructural unit runs in the same direction as Podtatranská kotlina basin. The borders between the partial units are considerably faulted and they manifested themselves during the Quaternary very dynamically. Likewise, the external borders of the central morphostructure are morphologically very pronounced. In the north it drops markedly towards *the Podtatranská brázda depression,* in the south the corresponding depressed marginal unit represents *the Horehronské podolie valley* (except the Breznianska kotlina basin).

*b) Fatra central morphostructure*

It is the lower one of two central morphostructures lying west of the dome centre of the West Carpathians. It is characterised by the north-south or diagonal orientation of the relief. It consists of by equally uplifted *the Veľká Fatra Mts.* and *the Malá Fatra Mts.* bordering on the relatively subsided *the Turčianska kotlina basin.* Both uplifted mountain ranges decline towards the basin by steep fault scarp with facets. We have included also *the Žiar Mts. and the Starohorské vrchy Mts.* into the Fatra central morphostructure. The nature of these morphostructures (except the massif Veľký Choč Mt) is that of less uplifted units joining higher central morphostructure. Their lower position is the result of stronger effect of the transversal fault tectonics (Lacika - Gajdoš, 1997).

### 1.1.2 Transitive morphostructures of the West Carpathian dome

The transitive part of the West Carpathian dome is less uplifted than the central and more uplifted than the peripheral one. Amplitude of the uplifts of the partial morphostructures is less pronounced, i.e their relief is less contrasting than in the central part of dome. This unit consists of five lower structures, which differ from each other by the composition of elevation and depression and by the properties of the passive structures expressed in relief. In other words, the mosaic of mountains and basins varies.

*a) the Beskydy transitive morphostructure*

There is Beskydy flysch morphostructure in the north of Slovakia and south of Poland. The Polish part of morphostructure passes the boundary northerly of the Tatra Mts. and joins the western and eastern Slovak parts to one entity. The western and eastern parts of the Beskydy flysch morphostructure are symmetrical (for instance the Skorušinské vrchy Mts. and the Spišská Magura Mts.). This unit is characterised by a distinct zonation with arch-shaped zones concentrically arranged around the centre of the West Carpathians. The zones are prevailingly identical with the axes of the flysch and klippen passive morphostructures. The contemporary valley network is based in the young generation of faults often not oriented in direction of the old structural axes.

There are partial morphostructures dominantly arranged in south-west -- north-east strike on the western wing of the West Carpathian dome. They are characterised by a distinct two-level composition of blocks. The elevation zones regularly alternate with depression zones. The higher level is formed by massive plateau-like uplands (*the Vysoké Javorníky Mts, the Turzovská vrchovina Mts., the Kysucké Beskydy Mts, the Oravské Beskydy Mts, the Oravská Magura Mts.* and *the Skorušinské vrchy Mts.)* locally containing well-preserved remains of the middle planation surface in the altitude 900-1 000 metres. Mountain ridges usually decline by faceted slopes towards the submotane forms and basins. The highest uplifted blocks are situated on the massif Babia Hora and Pilsko areas, altitudes of which are comparable for instance to both, Veľká and Malá Fatra Mts. The lower units are represented by a zone of subsided blocks (valleys, submotane, intermontane forms and basins) starting by the narrow *the Považské podolie valley passing the Nízke Javorníky Mts, the Kysucká vrchovina Mts., the Podbeskydská vrchovina Mts.* and ending by *the Oravská kotlina basin.*

The territory of the eastern flysch transitive morphostructures is expressively differentiated into a high uplifted group of blocks (*the Spišská Magura Mts., the Levočské vrchy Mts. and the Čergov Mts.)* and a relatively subsided group of blocks (*the Ľubovnianska kotlina basin* and *the Spišsko-šarišské medzihorie foreland).* The system of less uplifted morphostructures - intermontane forms *(the Pieniny Mts, the Ľubovnianska vrchovina Mts.* and *the Bachureň Mts.)* is also rather extensive. The highest mountains are sharply individualised, they have a distinct central ridge and submontane blocks. Two-level composition (the Levočské vrchy Mts.) and asymmetry (the Spišská Magura Mts.) occur in these units. General relief shapes are similar to the Central Slovakian volcanic mountains. There are well-preserved remains of the middle planation surface in the mountains. The depressions in this area are bordered by faults and underlined by selectively acting erosion.

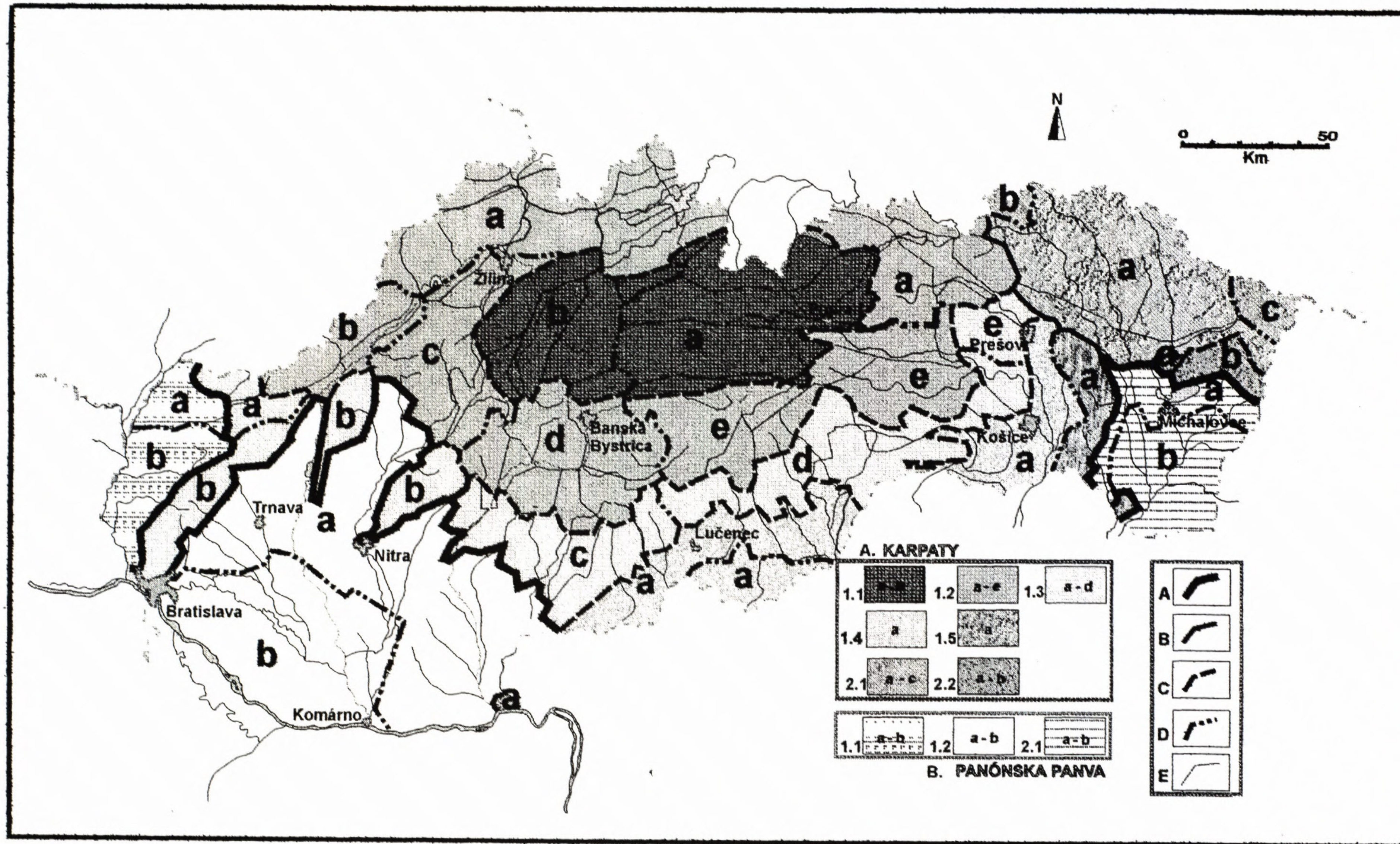



*Fig. 3 Proposal of the morphostructural division of Slovakia*

*A. Carpathians: 1. West Carpathians, 1,1 Central morphostructures of the West Carpathian dome,a. Tatra central morphostructure, b.Fatra central morphostructure; 1.2 Transitive morphostructures of the West Carpathian dome, a. Beskydy transitive morphostructure, b. Moravian-Slovak transitive morphostructure, c. Strážov transitive morphostructure, d. Central Slovak transitive morphostructure, e. Rudohorie transitive morphostructure; 1.3 Marginal morphostructures of the West Carpathian dome, a. Myjava marginal morphostructure, b. West Carpathian marginal morphostructures, c. Central Slovak marginal morphostructure, d. Rudohorie marginal morphostructure, e. Šariš marginal morphostructure; 1.4 Southern depressed morphostructures, a. Lučenec-Košice morphostructural depression; 1.5 Southern elevational morphostructures, b. Matra-Slaná morphostructural elevation* *b) the Slovak-Moravian transitive morphostructure*

This morphostructure is the westernmost unit of the 4th hierarchical level within the transitive part of the West Carpathian megamorphostructure. Its larger part lies in the Moravian territory. It includes a larger northern part of *the Biele Karpaty Mts.* and also larger southern part of *the Považské podolie valley* (the Ilavská kotlina basin and Trenčianska kotlina basin). The morphostructure has a notable two-level composition. Upper horst-like Biele Karpaty Mts is built-up by flysch rock, lower level is represented by a system of relatively subsided blocks of Považské podolie valley. The narrow zone of the limestone mountains represents an interference between the mountains and basins. But the active component structure (active faults) appear as a dominant relief-forming factor.

*c) the Strážov transitive morphostructure*

This morphostructure includes a group of mountains and basins in the central Považie and Horné Ponitrie regions. The tectonically less differentiated *Strážovské vrchy Mts.* represent the heart of the area. Notable passive structures (klippens, basins etc.) are evident in these mountains and in the neighbouring *Súľovské vrchy Mts.* Relatively subsided morphostructures in the periphery of unit are in minority (*the Považské podolie valley, the Žilinská kotlina basin* and *the Hornonitrianska kotlina basin).*

*d) The Central Slovakian transitive morphostructure*

There is a transitive morphostructure SW of the West Carpathian dome, which includes the northern area of the volcanic Slovenské Stredohorie. Its geological structure was analysed in detail by Konečný, Lexa & Planderová (1984) and Kalinčiak, Konečný & Lexa (1989). This territory is very expressively differentiated into uplifted group of blocks (mountains) and a relatively subsided group of blocks (basins). The primary volcanic land forms were almost completely destroyed in this part of the Slovenské Stredohorie, with the exception of *the Poľana Mts.* and *the Javorie Mts.*, where some traits of the original Neogenic stratovolcanoes are recognisable (Lacika 1993 and 1997a). Recent mountains of this unit are horst-like morphostructures dissected into a multidirectional system of ridges and valleys, especially *the Vtáčnik Mts., the Kremnické vrchy Mts.* and the northern part of *the Štiavnické vrchy Mts.* (Lacika 1997b). The north-southern orientation of the geomorphologic networks in this area is prevailing (from the area Veľká Fatra Mts. north of the Danube valley in the south). Structural cascades formed in the consequence of different rock resistance of the destroyed stratovolcanic structure, are evident in a more detailed scale, Some remains of the Neogene planation occur, for instance in the foreland of the Vtáčnik Mts otherwise these land forms are relatively rare in this area (with the exception of Kunešovská Planina plateau in the Kremnické vrchy Mts). Asymmetry of the uplifted blocks is relatively frequent (for instance Kremnické vrchy Mts). *The Zvolenská kotlina basin* is the internally most complicated structure in the area with several partial elevations and depressions. On the other hand, *the Žiarska kotlina basin* is simple, though very dynamically developed. *The Pliešovská kotlina basin* is particular for the absence of sedimentary filling.

*e) the Rudohorie transitive morphostructure*

This massive morphostructure lies south of the centre of the West Carpathian dome. It includes *the Veporské vrchy Mts., the Stolické vrchy Mts., the Volovské vrchy Mts. and the Spišsko-gemerský kras* area. Uplifted blocks are relatively expressively individualised in its northern side compared to the longitudinal depression of the Horehronské podolie valley or the Hornádska kotlina basin. They decline little by little and in a step-like manner towards the peripheral foreland in the south except the steep fault contact on the border of the Rožnavská kotlina basin in the south and the Košická kotlina basin in the south-east. Tectonic lines are manifested in the Rudohorie morphostructure in ground-plan only, less in the vertical dissection of relief. The central part of the unit carries extensive remains of the Neogenic planation surfaces in the altitude above 1 000 m. The western and eastern parts of this morphostructure are relatively wide in north-southern direction. On the other hand, the middle part of it (in the Dobšiná town area) with its visible reduction of width allows the immediate contact between the centre and periphery of the West Carpathian dome. The system of the linear geomorphologic network related to Murán faults is an important morphostructural element.

### 1.1.3 The marginal morphostructures of the West Carpathian dome

Except the Juhoslovenská depression, this marginal morphostructure is the least uplifted part of the West Car-

*Fig. 3 – continuation*

*2. East Carpathians: 2.1 Outer zone morphostructures of the East Carpathians, a. Beskydy transversal flysh morphostructure, b. Busov flysh morphostructure, c. Poloniny flysh morphostructure; 2.2 Inner zone morphostructures of the East Carpathians, a. Humenné non-volcanic morphostructure, b. Vihorlat volcanic morphostructure*

*B. Pannonian Basin: 1. West Pannonian Basin, 1.1 Záhorie morphostructures of the Pannonian Basin, a. Chvojnice morphostructure, b.Bor morphostructure; 1.2 Danube morphostructures of the Pannonian Basin, a. Outer Danube morphostructure, b. Inner Danube morphostructure, 2. East Pannonian Basin, 2.1 East Slovakian morphostructures of the Pannonian Basin, a. Outer East Slovak morphostructure, b Inner East Slovakia morphostructure*

*Morphostructural borders: A. 1st level morphostructural boundaries, B. 2nd level morphostructural boundaries, C. 3rd level morphostructural boundaries, D. 4th level morphostructural boundaries, E. 5th level morphostructural boundaries* pathian dome. There is more or less uplifted and subsided mosaic of block within this unit. The mountains decline straight towards wide lowland protuberances between the peripheral elevations or towards the longitudinal Juhoslovenská depression. We have discerned five morphostructural units of the fourth hierarchical level in the periphery of the dome.

*a) The Myjava marginal morphostructure*

This morphostructure belongs to the smallest ones. It continues on the Moravian side of the boundary and represents the group of less uplifted marginal blocks on the south-west margin of the Beskydy transitive zone. There are *the Žalostinská vrchovina Mts.* (SW of the Biele Karpaty Mts.) and the Myjavská pahorkatina hilly land in this unit.

*b) The West Slovakian marginal morphostructure*

This uplifted group of blocks in the West Slovakia are arranged into the three mountain ranges: *the Malé Karpaty Mts., the Považský Inovec Mts.* and *the Tribeč Mts.*. They decline towards lowlands, usually by fault scarps. The two-level composition and asymmetry occur there. There are well-preserved remains of the Neogene planation in several places. The lowland protuberances originated in the Neogene, They are tectonic subsided blocks. The Malé Karpaty Mts were investigated by Jakál, Lacika, Stankoviansky & Urbánek, 1988 and 1990.

*c) The Central Slovak marginal morphostructure*

The dome periphery farther eastward of the previous unit makes up a group of the plateau-like mountains built by the volcanic rock studied by Konečný, Lexa & Planderová (1984) and Kalinčiak, Konečný & Lexa (1989). They belong to less uplifted and less differentiated mountains: *the Pohronský Inovec Mts.*, southern part of *the Štiavnické vrchy Mts., the Krupinská planina plateau, the Ostrôžky Mts. and small Novobanská kotlina basin.* The extensive plateaus of this morphostructure gradually decline southwards. More uplifted marginal blocks than the central ones can be found only in the south of the Krupinská Planina plateau (Lacika, 1994 and 1997a).

*d) The Rudohorie marginal morphostructure*

Southwards of Rudohorie morphostructure lies a group of less uplifted blocks of *the Revúcka vrchovina Mts.* researched by Hochmuth (1996). Its tectonic differentiation is more dense than the internal massive part of the Slovenské Rudohorie Mts. Individual step-like blocks are separated by valleys tracing the tectonic lines, which are directed of the Slovenské Rudohorie Mts. in the north to the Juhoslovenská depression in the south. There is a group of morphostructures in the eastern part of dome periphery, which includes *the Slovenský Kras plateau, the Holička Mts.* (part of the Volovské vrchy Mts.) and the *Čierna Hora Mts.* The Slovenský Kras plateau is the karstic area depending on its geological structure, a superficial plateau karst prevails (Mazúr & Jakál, 1969, Jakál, 1975, 1978 and 1983). Each of the three partial morphostructures is bordered by very sharp fault scarps declined towards the Juhoslovenská depression. The Slovenský Kras plateau declines towards *the Rožňavská kotlina basin* on the opposite side. This basin is the only negatively developed unit in the Rudohorie marginal morphostructure.

*e) The Šariš marginal morphostructure*

This morphostructure is represented by a group of less uplifted blocks built by flysch rock. It is a very dynamic unit, because it lies in an area of the shortest distance between the centre and the borders of the West Carpathians dome. There is *the Šarišská vrchovina Mts.* in the south. It is a mosaic of step-like blocks without central ridge (Harčár, 1962). The south-eastern ending of *the Spišsko-šarišské medzihorie foreland* lies more to north. This morphostructure is characterised by the Neogenic volcanic exots eroded to distinct isolated elevations. This morphostructure passes continuously to the Košická kotlina basin in the south-east .

### 1.1.4 The Southuthern depressed morphostructures

These morphostructures are considered a part of the tectonic deformation of the southern wing of the West Carpathian dome (Mazúr, 1979). They consist of the chain of basins arching around the unit 1.1.3. The creation and development of this longitudinal depression is evidently the result of the tectonic block-like movements and selective erosion and denudation. Subject of the ongoing discussion is which of these two groups of relief-forming processes was the dominating one.

*a) The Lučenec-Košice depression morphostructure.*

The continuous zone of four basins (interconnected over Hungary) two hilly lands *(the Bodvianska pahorkatina hilly land* and *the Abovská pahorkatina hilly land*) are situated in an area between Šahy and Prešov towns. The three basins are neighbouring with each other, but they are not part of the same draining area. *The Ipeľská kotlina basin* is morphologically sharply delimited by the steep southern slopes of the Krupinská Planina plateau. It is divided by the system of parallel symmetrical valleys passive faults. The valleys are directed towards the main Ipel valley in the south-east. *The Lučenská kotlina basin* and *the Rimavská kotlina basin* have a more complicated composition. Their north and south fault bordering are notable (with zigzag course). The asymmetry of the valley indicates their internal morphostructural heterogeneity, which is manifested by tectonic tilting of the individual blocks. A very young and dynamic morphostructure *the Cerová vrchovina Mts.* in the south was individualised in the Pontian (Lukniš, 1972), but its contemporary morphostructural composition originated in the Upper Pliocene - Holocene periods. This unit is built by relatively extensive basalt volcanic complex, activity of which began in the Pliocene and continued till the Quaternary (Vass - Elečko, 1992). The original volcanic land forms of this mountain were erosionally destroyed and got into inverse position. The Cerová vrchovina Mts. was uplifted into combined dome-horst type morphostructure (Vass - Pristaš - Elečko, 1992 and Lacika, 1989). The study of the river planation surface indicates high values of its Quaternary uplifts locally higher than 300 metres (Lacika, 1990). Frequent asymmetry and appearance of the tectonic intramontane basins suggest an intensive morphostructural differentiation of these young mountains. The ground plant of *The Košická kotlina basin* is complicated with several protuberances to the Slovenské Rudohorie Mts. This basin is bordered and segmented by a few active fault lines in various directions. The west-east fault system dominates in the southern part of basin, the north-southern faults, which predetermine the direction of the principal basin river, dominate in the north. The Turnianska kotlina basin in the south-west represents an inverse valley bordered in the South and North by the longitudinal fault, which had been active during the Pliocene and Pleistocene. This faults controlled the uplifting of the Slovenský Kras plateau and subsidence of the proper depression (Vass et al., 1994).

### 1.1.5 The southern elevational morphostructures

This elevation morphostructure represents southern border West Carpathian dome, which myself individualised tectonic uplifts.

*a) the Matra-Slaná elevation morphostructure*

The longitudinal system of mountains culminates in its north-east termination formed by less tectonically differentiated volcanic-fault morphostructure *Slanské vrchy Mts.* According to Dzurovčin (1990) the morphology of the meridionally oriented morphostructure is given more by accumulation volcanics than by block upliftings along the system of faults. These mountains formed on north-south fault system, which are delimited by much higher blocks of the Košická kotlina basin and much lower blocks of the Východoslovenská Nížina lowland. Volcanics of the linearly arranged Neogene volcanoes covered a tectonic step-like blocks declined eastward. Their fault bordering is less expressive towards the Košická kotlina basin than towards the other side. *The Zemplínske vrchy Mts.* represent a horst-like morphostructure with unusual position. The system of uplifted blocks is enclosed from three sides by subsided blocks of the Východoslovenská nížina lowland. *The Burda Mts.* are by faults bordered morphostructure structurally connected with Hungarian volcanic mountain range Borsszony behind the fault of the Ipeľ valley. These mountains represent the west limitation of the south Slovakian elevation morphostructure. The Hungarian mountain range beginning by the Pilis Mts which spread farther to the south-west is not considered by the Hungarian geomorphologists as a part of the West Carpathians (Pésci, 1970). According to Mazúr (1979) they should be included in the West Carpathians.

### 1.2 The East Carpathians

The East Carpathians reach the territory of Slovakia by only by their western border only. They consist of two parts and their arrangement is zonal.

### 1.2.1 Outer zone morphostructures of the East Carpathians

The character of this unit is a transversally widely opening depression (intermontane type) between the West Carpathians and higher eastern part of the East Carpathians. The axis of this depression is north-south oriented. It follows the Ondava river valley. The Nízke Beskydy Mts appear as a northern continuation of the Východoslovenská Nízina lowland (its tectonic subsidence). The is a more uplifted group of blocks of the Bukovské vrchy Mts north-east of the Nízke Beskydy Mts. The upper blocks of the Busov Mts. are situated in the north-west.

*a) The Nízke Beskydy depression morphostructure*

This morphostructure is consists of three geomorphologic units: *the Ondavská vrchovina Mts., the Laborecká vrchovina Mts* and *the Beskydské predhorie foreland.* The shape of the Nízke Beskydy morphostructure is that of a wide shallow transversal depression, lower than the Čergov Mts, the Bukovské vrchy and the Slanské vrchy Mts. The Východoslovenská nížina lowland lies in lower position only. Morphostructure was analysed by Harčár (1995 and 1997). It is differentiated into a great amount of small blocks. The blocks are not organised into a well-marked hierarchically arranged system. There is not any central ridge or central depression in this morphostructure, only monotonous alternating of low ridges and valleys. The NW-SE and N-S lines dominate in the geomorphologic ground-plan. The NW-SE lines belong to the Paleogene geological structure, N-S lines are linked to younger faults. An expressive inverse relief occurs in some areas. The Beskydské predhorie foreland represents a zonally arranged less uplifted morphostructure. It looks as a foreland of the Ondavská vrchovina Mts. and the Laborecká vrchovina Mts. in the West and as wide valley between the Bukovské vrchy Mts. and the Vihorlat Mts. in the east. This morphostructure is differentiated by transversal faults.

*b) the Busov elevation morphostructure*

There is one partial morphostructure in the Busov elevation morphostructure. The are *the Busov Mts.* This less differentiated, massive mountainous unit like near Čergov Mts. is build by rock outer flysch, dominantly by sandstone, lithology of which emphasizes the elevation shape of morphostructure and relief inversion.

*c) the Poloniny elevation morphostructure*

This unit comprises only one partial morphostructure - *the Bukovské vrchy Mts.* This expressive elevation rises above the Nízke Beskydy Mts. The massive active morphostructure has a central ridge which reaches its highest altitude in the territory of Poland and Ukraine (over 1 300 m above the sea level). It has a two-level composition with vast foreland.

### 1.2.2 Inner zone morphostructures of the East Carpathians

This morphostructure includes the whole of the Vihorlatské vrchy Mts divided into two units of the 4th hierarchical level.

*a) The Humenné morphostructure*

This small morphostructure is identical to *the Humenské vrchy Mts.* in the western part of the Vihorlatské vrchy Mts. It is not volcanic or massive. Its blocks are built by the Mesozoic rock in an expressively isolated position. Morphostructure is less uplifted than the surrounding volcanic Vihorlat Mts. The group of blocks is limited by the longitudinal faults and differentiated by a transversal one. The Laborec river valley traces one of them.

*b) The Vihorlat volcanic morphostructure*

This volcanic and relatively massive morphostructure is divided into *the Vihorlat Mts.* and *the Popriečny Mts.* (the eastern part of the Vihorlatské vrchy Mts.) Kalinčiak, Konečný & Lexa (1989) studied its volcanic structure. The system of transversal tectonic divides the morphostructure by a transversal depression in two massifs. The Vihorlat Mts. group of blocks is individualised by expressive NE-SW faults. The transversal NW-SE faults in the Vihorlat Mts. become longitudinal in the Popriečny Mts. This different tectonic ground-plan changes orientation of the main ridge of the eastern part of the morphostructure.

### 2. The Pannonian Basin

The Pannonian Basin consists of three Slovak lowlands. Each of them is a part of bigger lowland unit, and their bigger parts lye out of Slovakia. The lowlands are bounded and divided by elements of the fault tectonics. The West Pannonian Basin consist of the Záhorská nížina lowland and Podunajská Nížina lowland. Východoslovenská nížina lowland belongs to the East Pannonian basin.

### 2.1 The West Pannonian Basin

### 2.1.1 The Záhorie morphostructures of the Pannonian Basin

The Záhorská nížina lowland belong to bigger lowland unit, which continues over the boundary of the river Morava to the Austria and the Czech Republic. Its boundaries with neighbouring elevation morphostructures follows mostly an active fault (more expressive with the Malé Karpaty Mts, less with the Myjavská pahorkatina hilly land).

*a) The Chvojnícka morphostructure*

The Chvojnícka morphostructure lies in the northern part of the Zahorská nížina lowland. It consists of *the Chvojnícka pahorkatina hilly land, the Gbelský Bor* and *the Slovak part of the Dolnomoravský úval lowland.* It has a mosaic of high lowland type blocks, which are massive, less differentiated and plateau-like. Plateaus reach the altitude above the sea level over 400 m in the Zámčisko area. The subsided blocks during the Quaternary are situated in the West (near Holič town).

*b) The Bor morphostructure*

Borská morphostructure stretches over *the Borská Nížina lowland* excluding the Gbelský Bor area. It has been studied by Škvarček (1971). The Malé Karpaty Mts. are bordered by a narrow longitudinal Podmalokarpatská Znízenina depression, which is dissected by transversal faults into less uplifted and more subsided system of blocks. An intense Quaternary subsidence of this depression has accelerated their filling by alluvium of the brooks from the Malé Karpaty Mts. The western part of Záhorská nížina lowland appears as relatively stable morphostructure. Its very moderate tectonic mobility is indicated by asymmetry of the terracing system of the Morava river, which is well developed in the left (Slovak) side. Probably the effect of a westward tectonic tilting caused gradual migration of the Morava in the same direction during the Quaternary.

### 2.1.2 The Danube morphostructures of the Pannonian Basin

The Podunajská morphostructure is bordered by faults with neighbouring elevation morphostructures of the West Carpathians. It is divided into two partial morphostructures.

*a) The Danube outer morphostructure*

This morphostructure includes *the Podunajská pahorkatina hilly land* only. It has a position of the transitive morphostructure between strongly subsided centre of lowland and surrounding positively developed mountainous morphostructure. The lowlands protuberances reach northwards between the mountain ranges of the West and Central Slovak external volcanic morphostructure. One of them (near the Bánovce town) directly contacts with the transitive morphostructures of the West Carpathian dome. The Podunajská pahorkatina hilly land is arranged into a system of alternating wide valleys and the lowland hills. The Váh river very intensively agrades in its valley between the Nové Mesto nad Váhom and Sereď towns, suggesting the Quaternary subsidence. This depression neighbours with the second subsided block in the southeast with recent tectonic tilting (Stankovinansky, 1993) There is also longitudinal depression at the foot of the Malé Karpaty Mts. analogue to depression in the opposite side of this horst morphostructure. This depression is cut by several active transverse faults. Some of them break the depression between the Modra town and Častá village (Feranec - Lacika, 1991). Geomorphologic development of entire morphostructure was influenced by intensive subsidence in the south lying neighbouring central blocks of the Podunajská nížina lowland. Large alluvial fan of the Danube river pushes back the lower Váh river. This geomorphologic process causes a bend of Váh river towards south-east close to Sereď town. Other considerable change of a hydrological and structural networks of the Podunajská nížina lowland developed on an the area of the lower Nitra and Zitava rivers. They flew directly down the old Žitava valley across the Hronská pahorkatina hilly land towards the Hron river valley as recently as in the Middle Pleistocene (Harčár, 1975 and 1981). There are several land forms related to the tectonic movements in the Podunajská pahorkatina hilly land, for instance rectangular and asymmetrical valley texture in the Hronská pahorkatina and Nitrianska pahorkatina hillylands (wide surroundings of the Vráble town).

*b) the Danube inner morphostructure*

This morphostructure is the deepest Quaternary tectonic depression in Slovakia .It includes the Žitný ostrov area and adjacent less subsided blocks of *the Podunajská rovina plain.* The Danube river looses its transport energy leaving the Malé Karpaty Mts Danube and its alluvial material is deposited into an intensively subsided central depression. Maximum thickness of the alluvial accumulation is more than 500 meters in the central part of depression (Halouzka, 1994). Man has entered into this natural relief-forming story by construction of dike systems and water works and stopped the process of depression. That is why in the territory of Žitný ostrov several shallow depressions originated, named by Lukniš & Mazúr (1959) "mokrade".

### 2.2 The East Pannonian Basin

#### 2.2.1 The East Slovakian morphostructures of the Pannonian Basin

This morphostructure has a complicated ground-plan. This lowland has no centre of subsidence. The plains are more typical here than hills in it is a trait that distinguishes it from the Podunajská nížina lowland.

*a) The East Slovakian outer morphostructure*

The Východoslovenská pahorkatina hilly land is situated in the circumferential part of the Východoslovenská nížina lowland. The edge of the lowland consists of a group of upper blocks higher than internal morphostructure and lower than the surrounding mountainous blocks of the Slanské vrchy Mts. and Vihorlatské vrchy Mts. They are very close to centre of the West Carpathians dome in the north-west. This fact causes the maximum dynamism of the local fluvial geomorphologic systems. The Pozdišovský chrbát lowland ridge reaches farthest in the Východoslovenská nížina lowland, between the Ondava and Laborec river valleys. There is a complicate system of blocks under the Vihorlatské vrchy Mts (surroundings of the Sobrance town).

*b) The East Slovakian inner morphostructure*

This morphostructure consists of *the Východoslovenská rrovina plain.* It is a complicated system of the blocks that subsided in the Neogene and Quaternary mobility of which causes frequent changes of the hydrological and geomorphologic networks (Borsy - Felefyházy, 1983). Subsided blocks are mostly bordered by N-S and W-E fault systems. There are flat and badly drained land forms, their rivers often agrade. Water-logged territory is unsuitable for agricultural use.

### Conclusion

The basic morphostructural units of Slovakia surpass its state borders and some of its parts part lie in the territories of the neighbouring states. In other words, the morphostructural regionalization has an international dimension. The Carpatho-Balkanic Geomorphologic Commission is starting a multilateral research project. It will co-ordinate the morphostructural research in several Central-European and Balkan countries including Slovakia. This contribution is a part of the project.

At the same time this contribution was realised as a part of the project solution No. 2/4063 granted at the recommendation of the scientific grant agency VEGA.

### References

Borsy, Z & Félegyházi, E., 1983: Evolution of the network of water courses in the NE part of the Great Hungarian Plain from the end of the Pleistocene to our days. Quaternary studies in Poland, 4, Warszawa, 115-124.

Dzurovčin, L., 1990: Geomorfologická analýza strednej časti Slanských vrchov. Kandidátska dizertačná práca, archív Geografického ústavu SAV, Bratislava.

Feranec, J. & Lacika, J., 1991: Identification and analysis of a "gravity nappe" in the South-Eastern of the Malé Karpaty Mts. by using radar image. Proceedings of the Eight Thematic Conference on Geologic Remote Sensing. Volume I, Denver, Colorado, 663-675.

Halouzka, R., 1994: DANREG - Neotektonická mapa Podunajska na Slovensku (1:100 000). Manuskript, GÚDŠ Bratislava.

Harčár, J., 1962: Šarišská vrchovina. Geografické práce, III, 1-2, 1-268.

Harčár, J., 1975: Podiel tektoniky na kvartérno-geologickom a morfologickom vývoji Pohronskej pahorkatiny a doliny Žitavy. *Geografický časopis*, 27, 1, 25 - 29.

Harčár, J., 1981: Stručná charakteristika terás Žitavy a Podunajskej nížiny. *Geografický časopis*, 33, 1, 72 - 90.

Harčár, J., 1995: Reliéf Nízkych Beskýd. Časť A. Povodie Tople, Časť B. Povodie Ondavy. *Geographia Slovaca*, 8, GÚ SAV, p.96.

Harčár, J., 1997: Problémy morfoštruktúrnej analýzy Nízkych Beskýd. in: Harčár, J. & Nižňanský, B.: Zborník z konferencie "Krajina východného Slovenska v odborných a vedeckých prácach. Prešov, 105-110.

Hochmuth, Z., 1996: Geomorfologické pomery centrálnej časti Revúckej vrchoviny a priľahlých častí Rimavskej kotliny a Slovenského krasu. *Geografické práce* VI, 1,

Jakál, J., 1975: Kras Silickej planiny. Osveta Martin, 1-149.

Jakál, J., 1978: Morfoštruktúrna analýza a jej využitie pri typológii krasu. *Slovenský kras*, 16, 17-37.

Jakál, J. 1983: Krasový reliéf a jeho význam v geomorfologickom obraze Západných Karpát. *Geografický časopis*, 35, 2, 160-183.

Jakál, J., Lacika, J., Stankoviansky, M. & Urbánek, 1988: Morfoštruktúrna analýza Malých Karpát a priľahlých území. Rukopis, archív Geografického ústavu SAV. 1-186.

Jakál, J., Lacika, J., Stankoviansky, M. & Urbánek, J., 1990: Morfo strukturnyj analiz gornogo massiva Malych Karpat. *Geomorfologija*, 4, 37-42.

Jakál, J., Feranec, J., Harčár, J., Lacika, J. & Urbánek, J., 1992: Využitie radarových záznamov v geomorfológii. *Mineralia slovaca*, 24, 257-269.

Kalinčiak, M., Konečný, V. & Lexa, J. 1989. Štruktúra a vývoj neogenných vulkanitov Slovenska vo vzťahu k blokovej tektonike. *Geologické práce, Správy 88*, 79 - 105.

Konečný, V., Lexa, J. & Planderová, E., 1984. Stratigrafické členenie neovulkanitov Slovenska. *Západné Karpaty. Séria geológia* 9, Bratislava.

Lacika, J., 1989: Morfoštruktúrna analýza Cerovej vrchoviny. In Michaeli, E, ed. Zborník referátov z geografického seminára, Prešov. UPJŠ Prešov, 37-43.

Lacika, J., 1990: Transformácia vulkanického reliéfu na príklade Cerovej vrchoviny. Geografický časopis, 42, 4, Bratislava, 375-400.

Lacika, J. 1993. Morfoštrukturná analýza Poľany. *Geografický časopis*, 45, 2-3, 233-250.

Lacika, J., 1994: Príspevok k poznaniu veku zarovnaných povrchov v Slovenskom stredohorí. Geographia Slovaca 7, Bratislava, 81-102.

Lacika, J., 1997a: Neogene Paleosurfaces in the Volcanic Area of Central Slovakia. Paleosurfaces: recognition, reconstruction and environmental interpretation. Geological Society of London, Special Publication Series, No. 120, London, 203-220.

Lacika, J., 1997b: Morfoštruktúry Kremnických vrchov. *Geografický časopis*, 49, 1, Bratislava, 19-33.

Lacika, J. & Gajdoš, A., 1997: Morfoštruktúry Starohorských vrchov. Geografické štúdie. Prírodné prostredie stredného Slovenska - jeho ochrana a tvorba. Univerzita Mateja Bela, Banská Bystrica, 28-34.

Lukniš, M., 1972: Reliéf. In: Lukniš, ed., 1972: Slovensko II - Príroda, Obzor Bratislava, 124-202.

Lukniš, M. & Mazúr, E., 1959: Geomorfologické regióny Žitného ostrova. *Geografický časopis*, 6, Bratislava, 177-185.

Mazúr, E. 1965. Major features of the West Carpathians in Slovakia as a result of young tectonic movements. In: Mazúr. E. & Stehlík, O., eds. 1965. Geomorphological problems of Carpathians, SAV, Bratislava, 9 - 54.

Mazúr, E., 1979: Morfoštruktúry Západných Karpát a ich vývoj. Acta facultatis naturalium universitatis Comenianae. *Geographica* 17, Bratislava, 21-34.

Mazúr, E., 1980: Morfoštruktúry, mapa 1: 1 000 000. In: Mazúr, E. & Jakál, J., (1980): Atlas SSR. Veda Bratislava.

Mazúr, E. & Jakál, J., 1969: Typologické členenie krasových oblastí na Slovensku. *Slovenský kras*, 7, 5-40.

Pécsi, M., 1970: Geomorphological regions of Hungary. Studies in geography in Hungary, 6, Akadémiai Kiadó, Budapest 1-45.

Stankoviansky, M., 1993: Vývoj reliéfu južnej časti Trnavskej tabule. *Geografický časopis*, 44, Bratislava, 93-108.

Škvarček, A., 1971: Základné geomorfologické členenie Záhorskej nížiny. *Geografický časopis*, XXIII, 2, Bratislava, 133-136.

Vass, D., Elečko, M., Pristaš, J., 1990: Klenba Cerovej vrchoviny - mladá štruktúra na južnom Slovensku. *Geologické práce, Správy* 84, Geologický ústav Dionýza Štúra, 135-140.

Vass, D. & Elečko, M., eds.,1992: Vysvetlivky ku geologickej mape Lučenskej kotliny a Cerovej vrchoviny 1:50 000. GÚDŠ, Bratislava, 1-196.

Vass, D., Elečko, M., Horská, A., Petrík, F., Barkáč, Z., Mello, J., Radocz, G. & Dubéci, B., 1994: Základné črty geológie turnianskej depresie. *Geologické práce, Správy* 99, 7-22.

Vass, D., Began, A., Gross, P., Kahan, Š., Kohler, E., Krystek, I., Lexa, J. & Nemčok, J., 1988: Regionálne geologické členenie Západných Karpát a severných výbežkov panónskej panvy na území ČSSR. Mapa 1:500 000. Geologický ústav Dionýza Štúra.

*Slovak Geol. Mag. 4, 1(1998), 29–33*

# Petrology and chronology of the Vučje gneiss, Serbo-Macedonian massif, Yugoslavia

DRAGAN MILOVANOVIČ [1], VESNA MARCHIG [2] and MILORAD DIMITRIJEVIČ [1]

[1]Faculty of Mining and Geology, 11000 Beograd, Dušina 7, Yugoslavia
[2]Federal Institute for Geosciences and Natural Resources, D-3000 Hannover 51, Stilleweg 2, Germany

***Abstract.*** The Vučje Gneiss consists of K-feldspar, plagioclase (oligoclase, andesine), biotite, muscovite and quartz. Mineral and chemical composition suggest that they were originally igneous rocks, i.e. peraluminous granites.

The gneisses of Vučje have a geochemical signature that is comparable with that of granitoids of within-plate tectonic setting, and of syn-collision granites.

The geochronological data suggest that three main periods of tectonism, metamorphism and/or igneous activities occurred: Caledonian , Hercynian and Alpine.

***Key words:*** petrology, chronology, gneiss, Serbo-Macedonian massif

## Introduction

The Vučje gneiss belongs to the Serbian-Macedonian Massif (Dimitrijevič, 1959), composed of two metamorphic complexes.

**The Lower complex**, pre-Cambrian in age, consists of different gneisses (locally migmatitized), micaschists, quartzites and marbles (in lower horizons). This complex also includes granitic rocks of two ages: the Vlajna pluton at the boundary between the lower and the upper complexes (450 Ma, Upper Ordovician, Vukanovič et al, 1973), and the Bujanovac granitic pluton (347 Ma, Lower Carboniferous, Dimitrijevič, 1958).

**The Upper**, or **Vlajna complex**, unconformably overlying the lower one, contains the paleofloral and faunal remains showing its Riphean-Cambrian to Ordovician (and probably even younger) age. It consists of greenschist facies metamorphosed rocks. The first outcrops of this complex are located about 15 km west of Leskovac.

The Vučje gneiss is situated south of the Leskovac Neogene depression, in the neighbourhood of Vučje township (Fig. 1). This concordant, strongly foliated body has a gradual transition toward the adjacent metamorphic rocks. General shape of the **Vučje gneiss** body is roughly elipsoidal, outcropping over an area of about 4x2 km. Northern part of the body is cut by a young fault toward the Neogene basin of the Veternica river. In the eastern direction it is flanked by the Vlajna granitic body, and by the Vlajna dome to the south, with conspicuous masses of migmatites. During previous investigations the Vučje gneiss has been regarded as a migmatite, together with the surrounding rocks, and mapped as an eyed-amygdaloidal embrechite. No special studies were formerly performed. New

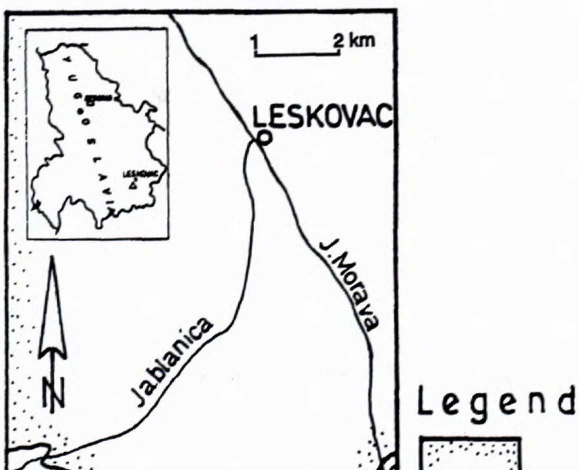



*Fig. 1. Locations and simplified geology of the Vučje Gneiss (after Dimitrijevič et al. 1966/67). Legend: 1. Quaternary and Neogene; 2. Hercynian granitoid rocks; 3. Crystalline schists of Lower complex of Serbo-Macedonian massif; 4. Gneisses of Vučje.*

investigations cover many aspects, including field relations, petrology, geochemistry and isotope geochemistry.

The purpose of this paper is to discuss the petrological and geochronological features of these rocks, basing on a substantial set of new analyses, and to present an idea of possible physical processes which controlled the thermal and structural evolution of this part of the Serbo-Macedonian Massif.

## Petrography

The Vučje gneiss consists of K-feldspar, plagioclase, biotite, muscovite and quartz. The accessories include zircon, apatite and tourmaline.

The gneisses are medium to coarse grained. The rocks vary from augen-to rarely banded gneisses. This banding is believed to be of structural-metamorphic origin because the original texture has not been preserved and the presence of augen structure requires a deformation. The general consistency in the orientation of foliation in the banded and augen gneisses suggests that the rock fabric was controlled by the regional strains. Leucocratic material in the outcrop ranges from the millimeter-thick layers and lenses to larger bodies as much as10 cm thick.

K-feldspar is a dominant mineral and constitutes between 35-40% of the volume of in investigated rocks. It occurs both as poikiloblasts and as small granoblastic matrix grains. Globular porphyroblasts of K-feldspar, as much as 5 cm in size, form 'eyes' in hand specimens. The crenulation folding in places deformed these eyes to an elipsoidal shape. Apparently, the K-feldspar porphyroblasts developed due to pressure solution of the same mineral in the protolith, although the metamorphic reactions may have also contributed to its development. The K-feldspar shows the Carlsbad twining and some perthitic and myrmekitic intergrowths. Some grains of K-feldspar have undulatory extinction, forming a lobate to sutural texture, but are not recrystallised along the grain boundaries. Locally, the K-feldspar contains as inclusions randomly oriented flakes of sericite.

Plagioclase is relatively fresh and twinned with polygonal boundaries. The grains are 0.1 to 0.5 mm in diameter and show no chemical zonation or significant compositional variations. This mineral also occurs as small anhedral grains included in K-feldspar. The evidence of retrogression to sericite is rare. This mineral constitutes as much as 20% of the rock.

Biotite is pale to red-brown and, together with rare flakes of muscovite, it defines the foliation of the gneisses. This mineral constitutes as much 20% of the rock. It scarcely enwraps large K-feldspar grains. Large biotite flakes (as much as 3 mm in size) are pleochroic, ranging from pale to reddish-brown, locally show some chloritic alterations, with, or without Fe-oxides, and may associate with muscovite to form patches. Some biotite flakes have cuspate contacts with the surrounding quartz-feldspathic matrix suggesting textural disequilibrium. Deformations, without mechanical discontinuity, also occur in some places. Biotite crystals are at places surrounded by a fine aggregate of K-feldspar and ilmenite.

Muscovite is scarce or totally absent. The flakes of this mineral sporadically occur as randomly oriented grains within biotite.

The quartz grains are elongated and show the deformation bands and undulatory extinction. This mineral shows a variety of recovery and recrystallization features, such as ribbon texture, separate grain boundaries and the development of fine-grained polygonal mosaics.

## Chemistry

### Bulk rock chemistry

Main and trace elements were determined on 5 carefully selected samples of Vučje gneisses using the X-ray fluorescence. The REE were determined by means of inductivelly coupled plasma mass spectrometer (ICP-MS). The analytical precision was tested using the international standards and was shown to be better than 5% for ten main elements and the REE. Analyses were performed at the Federal Institute of Geosciences and Natural Resources, Hannover (Germany).

The main and trace element contents and CIPW norms of the analysed rock samples are shown in Table 1. Mineral and chemical data suggest an originally granitoid composition. These rock have excessive molar $Al_2O_3$/ ($Cao+Na_2O+K_2O$) ratios, giving as much as 1.44% normative corundum (i.e. peraluminious granitic group, Maniar & Piccoli, 1989). The Vučje gneisses also follow a calcareous trend (Peacock, 1931) and chemical and mineral compositions correspond to granodiorites (Le Maitre 1989, Fig 2.).

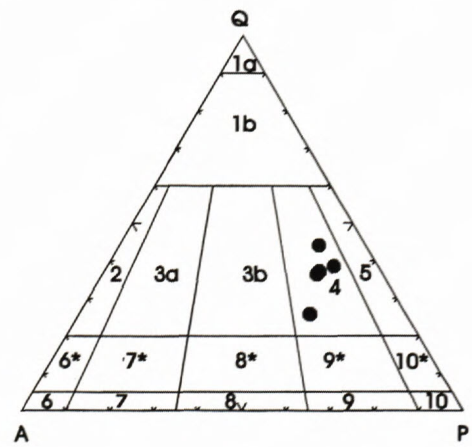



*Fig. 2. Plot of Vučje gneiss data on the normative Q-A-P diagram (Le Maitre, 1989).*
*Fields: 1a-quartzolite; 1b-quartz-rich granitoids; 2-alkali feldspar granite; 3a- syeno-granite; 3b- monzo-granite; 4- granodiorite; 5-tonalite; 6*- quartz alkali feldspar granite; 6-alkali feldspar syenite; 7*-quartz syenite; 7-syenite; 8*-quartz monzonite; 8-monzonite; 9-monzodiorite/monzogabbro; 10*- quartz diorite/quartz gabbro/quartz anorthosite; 10-diorite/gabbro/ anothosite.*

## Mineral chemistry

The minerals were determined using the optical microscopy and electron microprobe. All minerals were analysed using the Cameca electron microprobe stationed at the University of Hamburg. Analytical conditions were as follows: 20 kV acceleration voltage, 10 nA sample current, 10 s counting time. Natural and synthetic oxide and minerals were used as standards. Representative mineral analyses are shown in Tables 2-4.

*Table 1. Bulk rock chemistry of the Vučje gneisses*

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 68,68 | 73,55 | 71,56 | 70,82 | 70,03 |
| $TiO_2$ | 0.35 | 0.33 | 0.39 | 0.31 | 0.34 |
| $Al_2O_3$ | 16.15 | 12.92 | 14.54 | 14.39 | 15.13 |
| $Fe_2O_3$ | 0.12 | 0.47 | 0.59 | 0.34 | 0.39 |
| FeO | 2.50 | 2.63 | 2.02 | 2.81 | 2.59 |
| MnO | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 |
| MgO | 0.59 | 0.53 | 0.72 | 0.65 | 0.59 |
| CaO | 1.92 | 1.94 | 2.27 | 2.13 | 2.12 |
| $Na_2O$ | 4.49 | 3.70 | 4.17 | 3.91 | 3.86 |
| $K_2O$ | 4.09 | 2.36 | 2.21 | 2.91 | 3.01 |
| $P_2O_5$ | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 |
| LOI | 1.53 | 1.99 | 2.00 | 1.99 | 2.09 |
| Total | 100.57 | 100.56 | 100.62 | 100.42 | 100.30 |
| CIPW-norm | | | | | |
| Q | 20.41 | 36.56 | 32.05 | 29.73 | 29.15 |
| C | 1.11 | 1.01 | 1.45 | 1.22 | 1.93 |
| or | 24.17 | 13.31 | 13.06 | 17.20 | 17.79 |
| ab | 37.99 | 31.31 | 35.28 | 33.08 | 32.66 |
| an | 8.81 | 8.91 | 10.48 | 9.78 | 9.80 |
| hy | 5.46 | 5.27 | 4.43 | 6.06 | 5.42 |
| mt | 0.17 | 0.68 | 0.85 | 0.49 | 0.56 |
| il | 0.66 | 0.63 | 0.74 | 0.59 | 0.65 |
| ap | 0.25 | 0.25 | 0.28 | 0.28 | 0.25 |
| norm Pl | 18.81 | 22.14 | 22.89 | 22.82 | 23.07 |
| Trace elements (ppm) | | | | | |
| Sc | 6 | 5 | 6 | 5 | 6 |
| Y | 21.2 | 36.5 | 27.0 | 31.4 | 26.4 |
| Ba | 646 | 434 | 719 | 580 | 612 |
| B | 5.5 | 3.2 | 7.2 | 6.1 | 6.8 |
| Cs | 2.8 | 1.8 | 2.9 | 2.5 | 2 |
| Hf | 1.5 | 2.0 | 1.9 | 2 | 2 |
| Li | 18 | 13 | 20 | 16 | 18 |
| Mo | 1 | 1 | 1 | 1 | 1 |
| Nb | 24 | 21 | 22 | 22 | 21 |
| Pb | 19 | 17 | 13 | 18 | 17 |
| Rb | 119 | 66 | 88 | 90 | 92 |
| Sr | 248 | 271 | 333 | 311 | 298 |
| Ta | 2.3 | 2 | 2.2 | 2.1 | 2.2 |
| Th | 14.2 | 18.7 | 20.2 | 17.4 | 16.9 |
| U | 2.1 | 6.6 | 3.7 | 4.1 | 4.9 |
| Zr | 53 | 67 | 64 | 62 | 57 |
| La | 36 | 44 | 47 | 42 | 44 |
| Ce | 76 | 89 | 94 | 86 | 87 |
| Pr | 8 | 9 | 10 | 9 | 10 |
| Nd | 28 | 34 | 37 | 29 | 31 |
| Sm | 5.6 | 7.1 | 7.2 | 6.8 | 7.1 |
| Eu | 1 | 1 | 1 | 1 | 1 |
| Gd | 5 | 7 | 6 | 6 | 6 |
| Tb | 1 | 1 | 1 | 1 | 1 |
| Dy | 3.9 | 6.2 | 5.1 | 5.2 | 4.4 |
| Ho | 1.1 | 1.2 | 1.1 | 1.2 | 1.1 |
| Er | 8 | 3.4 | 2.5 | 3.1 | 2.8 |
| Tm | 1 | 1 | 1 | 1 | 1 |
| Yb | 1.7 | 3.1 | 2.1 | 1.9 | 2.5 |
| Lu | 1 | 1 | 1 | 1 | 1 |

*Table 2. Representative analyses of potassium feldspars from the Vučje Gneisses*

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ | 64.99 | 64.52 | 64.74 |
| $Al_2O_3$ | 19.00 | 19.20 | 19.12 |
| CaO | 0.04 | 0.42 | 0.00 |
| $Na_2O$ | 0.88 | 1.67 | 0.68 |
| $K_2O$ | 14.91 | 13.84 | 15.03 |
| Total | 99.82 | 99.65 | 99.57 |
| Number of ions on the basis of 8 oxygens | | | |
| Si | 3.0046 | 2.9735 | 3.0037 |
| Al | 1.0353 | 1.0429 | 1.0455 |
| Ca | 0.0020 | 0.0207 | 0.0000 |
| Na | 0.0789 | 0.1492 | 0.0612 |
| K | 0.8793 | 0.8136 | 0.8896 |
| or | 91.58 | 82.72 | 93.57 |
| ab | 8.21 | 15.17 | 6.43 |
| an | 0.21 | 2.11 | 0.00 |

*Table 3. Representative analyses of plagioclase from the Vučje gneisses*

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 62.86 | 61.75 | 61.76 | 61.96 | 63.77 |
| $Al_2O_3$ | 24.07 | 24.53 | 24.71 | 24.57 | 23.46 |
| CaO | 4.43 | 4.82 | 4.65 | 4.63 | 3.20 |
| $Na_2O$ | 9.17 | 9.11 | 9.25 | 9.09 | 9.73 |
| $K_2O$ | 0.24 | 0.12 | 0.17 | 0.14 | 0.27 |
| Total | 100.77 | 100.33 | 100.54 | 100.39 | 100.43 |
| Number of ions on the basis of 8 oxygens | | | | | |
| Si | 2.7556 | 2.7169 | 2.7084 | 2.7252 | 2.7955 |
| Al | 1.2436 | 1.2720 | 1.2771 | 1.2736 | 1.2121 |
| Ca | 0.2081 | 0.2272 | 0.2185 | 0.2182 | 0.1503 |
| Na | 0.7794 | 0.7771 | 0.7865 | 0.7752 | 0.8270 |
| K | 0.0134 | 0.0067 | 0.0095 | 0.0079 | 0.0151 |
| ab | 0.779 | 0.769 | 0.775 | 0.774 | 0.833 |
| an | 0.208 | 0.225 | 0.215 | 0.218 | 0.151 |
| or | 0.013 | 0.006 | 0.010 | 0.008 | 0.016 |

*Table 4. Representative analyses of biotite from the Vučje Gneisses*

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 34.56 | 34.49 | 34.04 | 34.69 | 35.63 |
| $TiO_2$ | 2.02 | 2.04 | 2.00 | 2.20 | 2.09 |
| $Al_2O_3$ | 17.20 | 17.06 | 17.40 | 17.07 | 17.19 |
| FeO | 25.80 | 26.10 | 26.09 | 25.41 | 23.49 |
| MnO | 0.27 | 0.22 | 0.22 | 0.23 | 0.25 |
| MgO | 6.55 | 6.71 | 6.62 | 6.68 | 9.10 |
| $K_2O$ | 9.09 | 9.26 | 9.05 | 9.33 | 9.49 |
| Total | 95.49 | 95.88 | 95.42 | 95.61 | 97.24 |
| Number of ions on the basis of 22 oxygens | | | | | |
| Si | 5.4335 | 5.4149 | 5.3686 | 5.4428 | 5.4335 |
| Ti | 0.2388 | 0.2408 | 0.2372 | 0.2596 | 0.2397 |
| Al | 3.1871 | 3.1567 | 3.2343 | 3.1565 | 3.0895 |
| $Fe^{2+}$ | 3.3922 | 3.4268 | 3.4411 | 3.3341 | 2.9957 |
| Mn | 0.0360 | 0.0293 | 0.0294 | 0.0306 | 0.0323 |
| Mg | 1.5349 | 1.5702 | 1.5562 | 1.5622 | 2.0684 |
| K | 1.8230 | 1.8545 | 1.8207 | 1.8673 | 1.8461 |

The analyses are the averages of 3-5 measurements made on mineral grains in the same thin section. Analysis of approximately 50 K-feldspar grains have shown a stable composition (Table 2). Also the plagioclase, analysed on some 30 grains, have shown an almost identical composition at the oligoclase-andesine boundary (Table 3). Coarser plagioclase grains (1 mm in diameter) neither show the chemical zoning nor significant compositional variations.

The composition of biotite (approximately 30 grains analysed, Table 4) is siderophylitic. The combination with nominal 4% of $H_2O$ content yielded a total average of only slightly more than 100%.

## Geohronology

Geochronological data may be relevant to two fundamental questions: (1) when the granitoid protolith formed and (2) when it underwent the metamorphism and cooling.

Three samples have been selected for U-Pb dating (on zircon), and for K-Ar dating on plagioclase, alkali feldspar and biotite. The isotopic age of mentioned minerals was determined by Yu. Pushkarev (VSEGEI, Sankt Peterburg).

The results are: 500 (±1.4) Ma for zircon; 265 (±30) Ma for plagioclase; 150 (±5)Ma for biotite and 130 (±10) Ma for K-feldspar.

The age value of the zircon is interpreted as the age of the granitoid magmatic (Caledonian ?) intrusion. The age value of plagioclase reflects the age of the Hercynian metamorphism, rejuvenated by the Alpine reworking. Alpine rejuvenation metamorphism is unquestionable, considering the biotite and K-feldspar K-Ar age values.

## Metamorphic conditions and evolution

The mineral assemblage in Vučje Gneiss does not allow to accurately determine the metamorphic pressures. Metamorphic temperature of in the mentioned rocks can only be obtained from the feldspar geothermometer of Whitney & Stormer (1977). On the basis of mentioned geothermometer (for a supposed pressure of 6 Kb) the metamorphic temperature for the investigated rocks falls within the range 450 to 530°C. Mineral association in Vučje gneisses, Pl+Bt+Kfs+Ms+Qtz also indicates that temperature of metamorphism of the investigated rocks is compatible with the lower part of the amphibolite facies, close to the boundary with the greenschist facies (about 530-550°C).

The metamorphic temperature of about 530-550°C should be referred to the Hercynian metamorphism, because the post-tectonic, Hercynian Vlaina granitoid is not metamorphic (Fig. 1, symbol 2). Therephore, when this granitoid was intruded, the Vučje gneisses were already metamorphosed.

The Alpine effects were only minor, probably only producing an isotopic rejuvenation, but not new minerals. This conclusion is consistent with the fact that Hercynian granitoids do not show any mineral alteration, indicating an Alpine metamorphism.

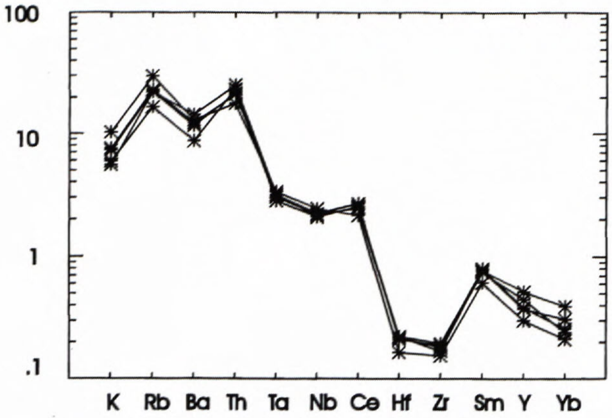



*Fig. 3. Multi element diagram of some representative Vučje Gneiss analyses, normalised to ocean ridge granite. The order of the elements and values of the normalizing constants are from Pearce et al. (1984).*

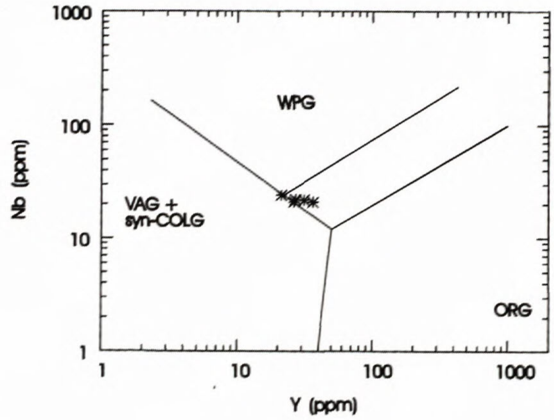



*Fig. 4. Plot of the Vučje Gneiss analyses on the tectonomagmatic discrimination diagram for granitic rocks according to Pearce et al. 1984. WP: within plate granites; VAG+syn-COLG: volcanic arc granites and syncollision granites; ORG: ocean ridge granites*

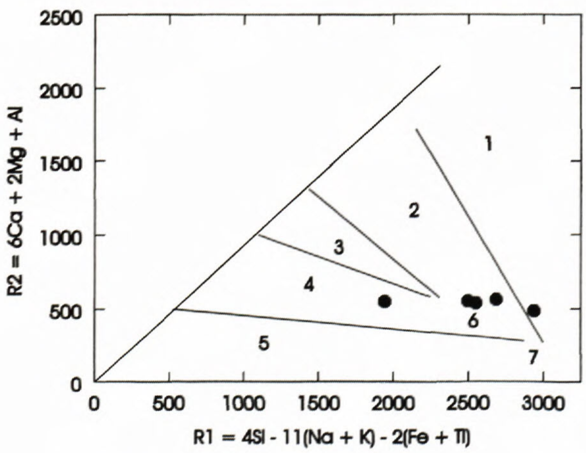



*Fig. 5. Plot of the Vučje Gneiss using the multicationig parameters*
*( Batchelor & Bowden, 1985).*
*Legend: 1 Mantle fractionates; 2 Pre-plate collision; 3 Post-collision uplift; 4 Late-orogenic; 5 Anorogenic; 6 Syn-collision; 7 Post-orogenic*

## Conclusion

Mineralogical and chemical compositions of Vučje gneisses suggest that they were originally igneous rocks i.e. peraluminous granitoids. This type of granitic magma is commonly considered as generated directly from partial melting of crustal materials.

For the purpose of the tectonic setting granites have received less attention than basalts as tectonic indicators. However the geochemical studies of Vučje gneisses have an important bearing on the interpretation of tectonic setting.

The gneisses of Vučje are characterized by enrichments in K, Rb, Ba, Th, Nb and Ce relative to Hf, Zr, Sm, Y and Yb (Fig 3).

These rocks, when plotted on a discrimination trace element diagram (Fig 4.), have a geochemical signature that is comparable with the granitoids from within-plate tectonic setting (Pearce et al. 1984). Classification schemes based on the main components (Peacock, 1931, Chappel & White, 1974, White & Chappel, 1977, Collins et al, 1982 etc) do not give significant indications for the tectonic classifications.

The chemical data of Vučje gneisses fall in the field of syn-collisional melts (Fig . 5, Batchelor & Bowden, 1985)

Based on the geological and radiometric results, three main periods of tectonism, metamorphism and/or igneous activities can be recognised: Caledonian, Hercynian and Alpine.

Primary (?) crystallization of granitic magma (zircon age) happened 500 M/a ago. This has been considered as the age of plutonic emplacement of granitic magma.

The mineral assemblages of Vučje gneisses is therefore dominated by an amphibolite facies equilibrium assemblage, which shows only minor overprinting by the fine-grained recrystallization. The last phase of crystallization of minerals pertains to the lower part of amphibolite facies of metamorphism (recrystallization of plagioclase and formation of augen K-feldspar). The plagioclase age (265 m/a) can indicate a period of tectono-metamorphic activity, probably related to Hercynian orogenesis, or may be a result of an Alpine overprint.

The greenschist facies metamorphism (recrystallization of K-feldspar and the isotopic reseting of biotite) relates to Alpine metamorphism (K-feldspar and biotite age).

*Acknowledgements*

Microprobe analyses were made at the University of Hamburg, Institute for Petrology and Mineralogy. Many thanks are due to B. Cornelisen for his technical assistance.

## References

Batchelor, R.A. and Bowden, P (1985). Petrogenetic interpretation of granitoid rocks series using multicationic parameters. *Chemical Geology*, 48, pp 43-55.

Chappel, B.W. and White, A. J. R. 1974. Two contrasting granite types. *Pacific Geology*, 8. pp 173-174.

Collins, W. J., Bearns, S.D., White, A.J.R., & Chappell, B.W., 1982. Nature and origin of A-type granites with particular reference to Southeastern Australia, Contribution of *Mineralogy and Petrology*, Vol.10, pp 189-168.

Dimitrijevič, M., 1958. The geology of the granite massif of Bujanovac, Rasprave zavoda za geoločka i geofizička istraživanja, Vol. VII, pp 1-148, Beograd

Dimitrijevič, M., 1959. Osnovne karakteristike stuba Srpsko-makedonske mase. I simpozijum SGD (unpublished).

Dimitrijevič, M.D., Petrovič, S.D., Cvetkovič, M.D., 1966/67. Crystalline schists of Pusta Reka and Toplica. *Zbornik radova Rudarsko-geoločkog fakulteta*, Vol. 9-10, pp 183-217, Beograd.

Le Maitre, R.W., (ed)., 1989. A Classification of igneous rocks and glosary of terms, *Blackwell*, Oxford, pp 193.

Maniar, P. D., Piccoli, P. M., 1983. Tectonic discrimination of granitoids. *Geological Society of America Bulletin*, Vol. 101, pp 635-643.

Peacock, M.A., 1931. Classification of igneous rock series. *Journal of Geology*, Vol. 39, pp. 54-67.

Pearce, J. A., Harris, N.B.W., and Tindle, A.G. 1984. Trace elements discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Geology*, Vol. 25., pp 956-983.

Vukanovič, M., 1973. Geology of Leskovac sheet, OGK, 1: 100 000, *SGZ*, Beograd, pp 1-57.

White, A.J.R. & Chappel, B.W. 1977. Ultrametamorpfism and granitoid genesis. *Tectonophysics*, Vol. 43, pp 7-22.

Whithey, J.A & Stormer, J.C., 1977. The distribution of $NaAlSi_3O_8$ between coexisting microcline and plagioclase and its effect on geothermometric calculations. *American Mineralogist*, Vol 62. pp 687-691.

Slovak Geol. Mag. 4, 1(1998), 35–52

# Lithobiostratigraphy of the Ždiar Formation of the Krížna nappe (Tatry Mts.)

MILAN POLÁK[1], ANNA ONDREJIČKOVÁ[1] and JÓZEF WIECZOREK[2]

[1]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovakia
[2]Geotermia Podhalańska S. A., Ul. Szymony 17A, 34 500 Zakopane, Poland

***Abstract:*** On the basis of lithobiostratgraphical study in Tatra Mts. (and Veľká Fatra and Malá Fatra Mts., Strážovské vrchy, Chočské vrchy and Nízke Tatry Mts.) the formation of Middle and Upper Jurassic radiolarian limestones and radiolarites in the Krížna nappe was distinguished as a new lithostratigraphic unit - the ŽDIAR Formation. The stratigraphic range of the Ždiar Formation was established as Upper Bathonian - Lower Kimmeridgian on the basis of radiiolarian microfauna.

***Key words***: Ždiar Formation, radiolarian limestones, radiolarites, microfacies, radiolarians, age, Krížna nappe, Tatry Mts., West Carpathians, Slovakia and Poland.

## Introduction

Several sections through the radiolarian limestones and radiolarites of the Krížna nappe in the Tatry Mts. were recently investigated and recorded as part of the project Geodynamic model of the Western Carpathians. This allowed us to obtain a direct paleontological information on the stratigrafic range of this Krížna nappe formation in almost all core mountains of the Western Carpathians.

As early as in 1925 Rabowski & Goetel and in 1932 Sujkowski assigned the Doggerian age to the radiolarite formation. This formation of the Tatra Mts. was studied in more detail by Lefeld (1974, 1981). Lefeld et al. (1985) accepted the concept of Birkenmajer (1977) who distinguished two formal stratigraphic radiolarite units in the Klippen belt, the lower - Sokolice Unit of probable Upper Bajocian - Bathonian age and the upper unit - the Czajakowa radiolarites of the Callovian - Oxfordian age. On the basis of these assumptions this author adopted a similar scheme for the whole Western Carpathian region and for the northern Tethyan margin. Most newer lithostratigraphic and biostratigraphic data refer to the Krížna nappe of the Western Carpathians (Polák & Ondrejičková 1993a, 1993b,1995).

## Lithology

We investigated several sections through the Upper Jurassic radiolarian limestones and radiolarites of the Krížna nappe in the Tatry Mts. Our attempt to find and to classify the radiolaria microfauna was succesful in the following sections:

- on the SE ridge of the Ždiarska vidla (the Havran partial tectonic unit),
- in the section Banie Huciska (Bobrovec tektonic unit) and
- in the section Gladki Uplaziańskie tectonic unit).

### Section: **Ždiarska vidla**

On the south-eastern ridge of the Ždiarska vidla there is a complete section through the formation of radiolarian limestones and radiolarites, which we refer to as the **type section of the Ždiar Formation**. (Fig. 2).

The immediate underlier is composed of a formation of dark-grey, marly, mottled limestones with scarce dark chert nodules, alternating with the dark-grey shales - (the Allgäu Member - Fleckenmergel). The age of the formation corresponds to the Sinemurian to Toarcian (Gaździcki et al., 1979, Lefeld et al., 1985).

The lower, some 50 cm thick part is made up of grey-green radiolarian limestones with a black radiolarite intercalation and noduless. It is suceded by a bed consisting of three thin strata (as much as 10 cm thick) of greenish radiolarites. The formation continues with the grey-greenish, bench-like (10 - 15 cm thick) radiolarian limestones that contain small black chert nodules. Another part (some 2 m thick) is composed of the red-violet friable radiolarites, grading into pink, green and pale-grey radiolarites with pale-grey limestone intercalations. The overlying part is made up of pale-grey, compact radiolarian limestones with small nodules of green-black cherts. After an interruption there follow thin-bedded to slab-like (5 - 10 cm thick) green-grey radiolarites with thin, grey limestone and shale intercalations. These are overlain by an about 1 m thick bed of green-grey, slab-like, partly desintegrating radiolarite, which ends with a bed of grey limestones with radiolarite nodules. The subsequent suite

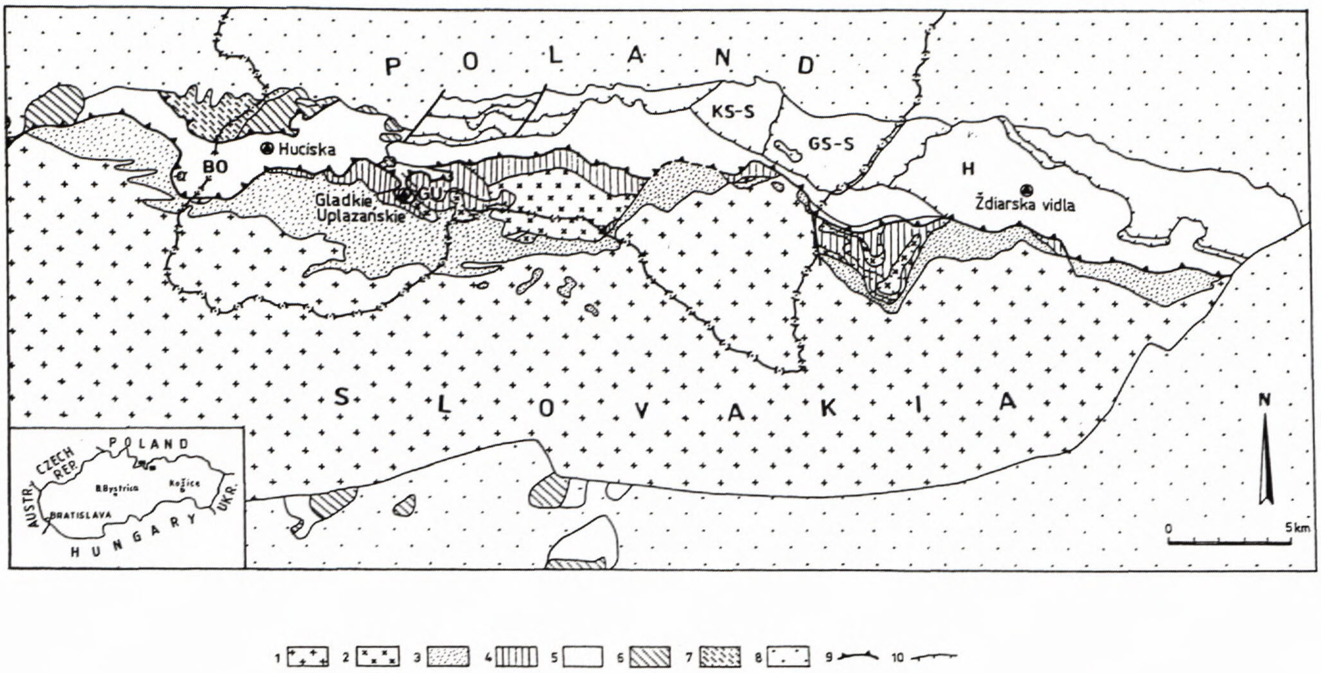



*Fig. 1 Localization of studied radiolarian-bearing profiles of Tatra Mts.*
1 - *Crystalline core of the Tatra Mts.*, 2 - *Crystalline rocks of allochthonous High Tatric units*, 3 - *Sedimentary cover of crystalline massif*, 4 - *Sedimentary rocks of allochthonous High Tatric units*, **5** - *Tectonic units of Krížna nappe (radiolarite bearing units)*: Bo - *Bobrowiec unit*, GU - *Gladkie Uplaziańskie unit*, KS-S *Kopy Soltysie-Siodlo unit*, GS-S - *Gesia Szyja-Skalki unit*, H - *Havran unit*, 6 - *Choč nappe*, 7 - *Furkaska-Koryciska unit (the highest tectonic unit of the Tatra Mts., ? Choč nappe)*, 8 - *Paleogene*, 9 - *Overthrust of the Krížna nappe*, 10 - *Other overthrusts*

is composed of the grey-green desintegrating radiolarites that end-up with the beds of grey limestones. The uppermost part of the formation (about 3 m thick) is composed of thin bedded to slab-like, grey-green, in its upper part even black radiolarites, with irregular grey limestone intercalationsf. These are overlain by red nodular limestones of the Jaseniny Formation (Kimmeridgian).

**Banie Huciska section**

The section occurs on the eastern slopes of Chocholowska dolina, on the south-western slope of the Kliny hill (1275 m). The whole section is part of the Homola Formation (Lefeld et al., 1985). In the lower part of the section there occur the Allgäu Member rocks (Fleckenmergel) of the Lotharingian age, which are overlain by the crinoid limestones with spongoliths and with Fe–Mn mineralized beds that were mined in the past (Krajewski & Myszka, 1958). The overlying, 3 - 4 meters thick suite is composed of the red, nodular, Adnet limestones of Toarcian age (Sokolowski, 1925).

The Adnet limestones are overlain by about 1 m thick grey-green, slab-like crinoid limestones with thin shale intercalations and with small chert nodules. The formation continues by an about 3 m thick assemblage of red, violet, slab-like radiolarian limestones that locally contain the green radiolarite bands. The next assemblage (about 9 m thick), is made up of green, grey-green, slab-like, 5 - 10 cm thick radiolarian limestones. In the lower part there occur beds and intercalations grey-green shales. Most radiolarites occur as nodules of elliptic shapes, oriented parallel to the bedding. Their size is as much as 30 cm across. The next assemblage (some 4 m thick) is represented by red, violet, slab-like, 10 - 25 cm thick radiolarian limestones alternating with beds and bands of red and pink radiolarites.

The whole section ends up with the red, violet, nodular, Kimmeridgian limestones and shales and with the Osnica Formation rocks.

**Gladkie Uplaziańskie section**

In this section, the condensed Jurassic - Lower Cretaceous sedimentation appears in full. The Allgäu Formation (Fleckenmergel) of Lotharingian - Toarcian age (Lefeld et al., 1985) and the crinoid limestones of Lower Liassic age directly overlie the radiolarian limestones and the radiolarites. The formation proper is in its lower part (about 2 m tick) composed of green radiolarian limestones with green radiolarite intercalations. These grade into a bed of red radiolarian limestones and radiolarites (some 2 m). Next bed is made up of grey, slab-like, pelitic limestones with green radiolarite intercalations. These are overlain by red, bedded, nodular limestones, grading into pseudonodular, red, marly limestones, probably of Kimmeridgian age. The upper part is made up of the Osnica Formation rocks of Tithonian - Lower Valanginian age.

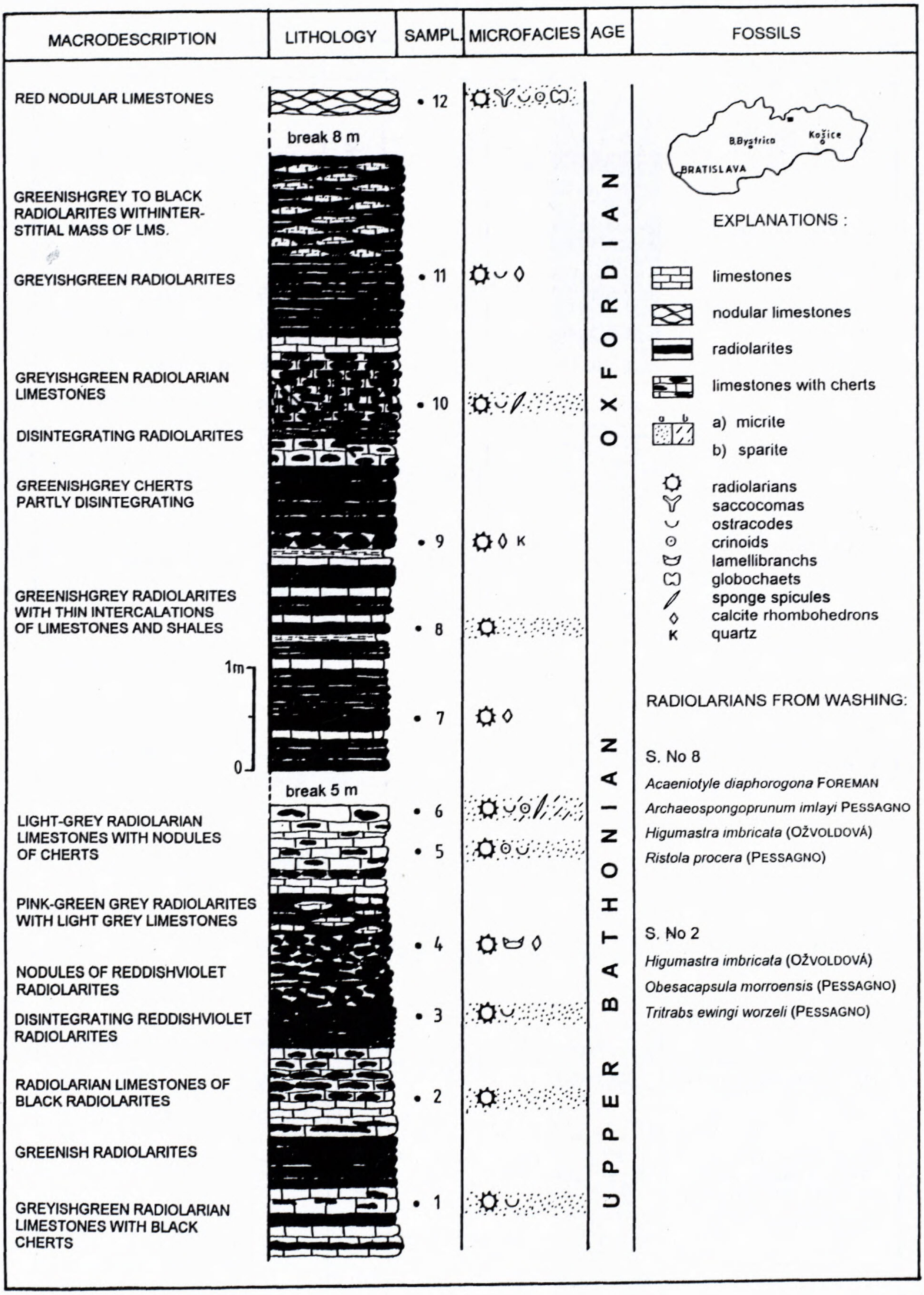



*Fig. 2 Type lithostratigraphical profile through the Ždiar Formation of the Krížna nappe. Locality: SE ridge of Ždiarska vidla - Belianske Tatry Mts.*

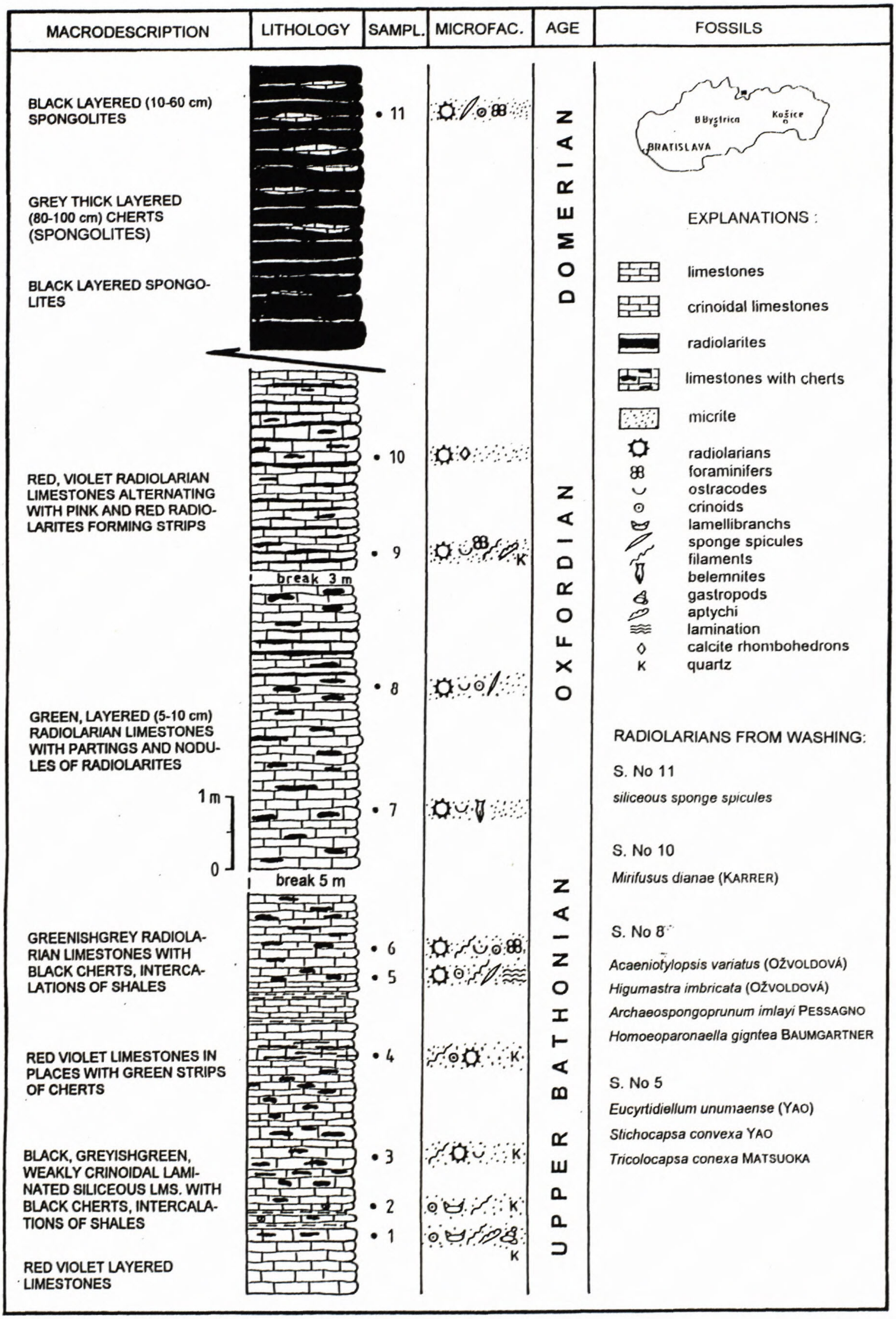



*Fig. 3 Lithostratigraphical profile through the Ždiar Formation of the Krížna nappe. Locality: Banie Huciska - Vysoké Tatry Mts.*

## Lithostratigraphy and microfacies

THE ŽDIAR FORMATION (new name of the lithostratigraphic unit)

*Name*: borrowed from the hilltop of the Ždiarska vidla (2146.0 m) in the Belianske Tatry Mts. On the south-eastern ridge there is a very well exposed sequence of Jurassic sedimentary beds of the Krížna nappe.

The type locality: any part of the area underlain by Middle to Upper Jurassic radiolarian limestones and radiolarites of the Krížna nappe, in any core mountain of the Western Carpathians.

*Type section:* south-eastern ridge of the Ždiarska vidla.

*Reference sections:* Banie Huciska, Gladkie Uplaziańskie (Polish part of the Tatry Mts.) Zázrivská dolina (Malá Fatra Mts.), Trlenská dolina (Veľká Fatra Mts.), Lúčky (Chočské vrchy hills), Zliechovská dolina (Strážovské vrchy hills).

The formations are predominated by the radiolarian, partly quartzose, mostly bedded, variegated limestones (grey, black, green, red, or violet). The $SiO_2$ contents range between 15 and 45 %.

Structurally, most of them are biomicrites, while biomicrosparites of the wackestone type are less common. The most common microfacies in the limestones of the above mentioned formation is the radiolarian microfacies. The ratio of radiolarians, which are a rock-forming component, ranges between 40 and 85 %. Most radiolarians are calcified, but a small ratio preserved their original siliceous tests. The probability of finding suitable micropaleontological material also depends on the rate of preservation of the original composition. Almost 60 % of the radiolarians are the *Spumellaria* forms, and the rest are the *Nasellaria* forms.

Both, the form and the mode of preservation of the radiolarians are subject to strong variation (see Polák & Ondrejičková, 1993b). While the ostracods, and the globochaetes are commonly present, the crinoid segments, apart from some basal parts of the section Huciska, where they may represent as much as 50 % of the total fossil remnants, are less abundant. Here, the lamellibranchiata fragments and the aptychi also occur. In the upper parts of the sections, the ratio of filaments, of the detritic aptychi and of the segments of planktonic crinoids *Saccocoma* sp. increases. In the section Huciska the ratio of sponge spicule sections distinctly increases upwards. Less common are the foraminifera (*Frondicularia* sp., *Nodosaria* sp.) segments. In one case a segment of the belemnite rostrum was encountered. Sporadically occurs the clastic admixture in the form of angular quartz fragments of aleuritic size.

The radiolarites represent the second most important rock- forming component of the Ždiar Formation. In the Ždiarska vidla section they make up some 65 % of the rock. However, in the other sections their presence is much lower. Most radiolarites in limestones have a form of irregular elliptic nodules of various size. Almost all are oriented parallel to the bedding. Many nodules coalescce to produce the radiolarite beds and bands.

The radiolarites, as well as the limestones, have various colours ranging from black, through grey and green to red and violet tints.

As far as their microfacies classification is concerned, we assign them to the silicic-calcitic biomicrites with a high frequency of radiolarians, predominantly of the *Spumellaria* type, composed mainly of the original, fine-grained quartzose matrix. Of the organic remnants there occur scarce ostracods and very scarce sponge-spicules. The presence of euhedral, autigenic rhomboids, made up of calcite, or dolomite, respectively, is a characteristic feature. These rhomboids are almost always bound to the organic remnants, which commonly make up their central part.

In the basal part of the Huciska section (HC-5) the laminated textures composed of the fagments of miscellaneous organic detritus, mainly of the Crinoid segments and filaments, with the indications of gradational bedding, were encountered. These alodapic components represent the distal turbidite (Walker, 1967), or the microturbidites (Schläger & Schläger, 1969), remnants, respectively.

## Biostratigraphic assessment

The study of radiolarites and of the radiolarian limestones from the Krížna nappe of the Tatry Mts. is a follow-up of the previous studies that focused on their origin, biostratigraphy and lithostratigrafic position in the different Western Carpathian tectonic units (Polák & Ondrejičková, 1993b).

Generally, a conclusion may be drown that despite their frequency in the sediments studied only a few gave such an extractable association that can be unequivocally biostratigraphically interpreted. The reason is poor preservation of their tests, which is due to calcification, fragmentation and deformation of the host rock.

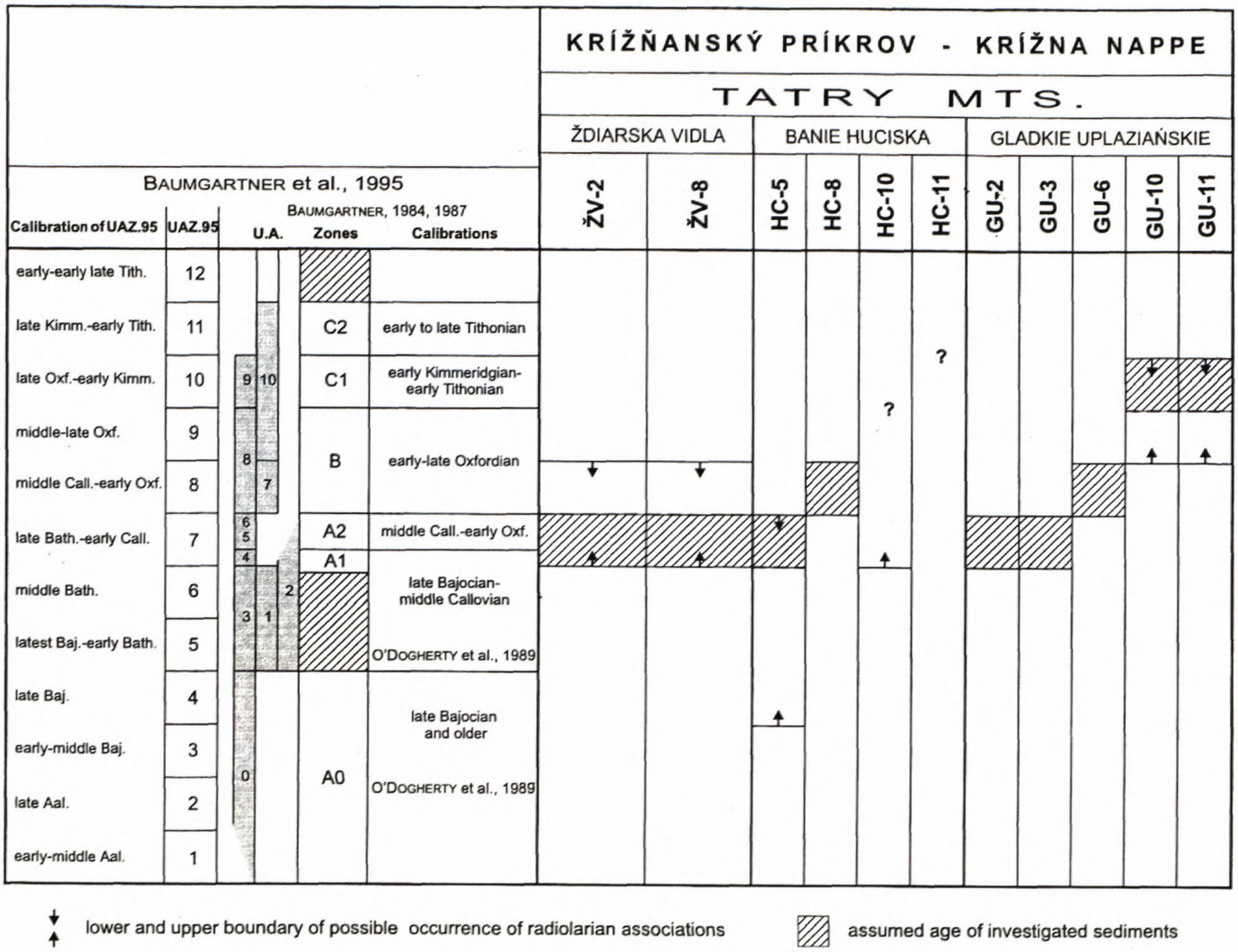
Biostratigraphic assessment of radiolarian associations is supported by their presence in the zones (UAZ) that correspond to appropriate periods in the chronostratigraphic range, as referred to by Baumgartner et al. (1995) in their latest paper.

It must be noted that the zoning and its sequential order underwent (since its establishment) several modifications (Baumgartner, 1984, 1987, O'Dogherty et al., 1989) and if the latest zoning is to be applied (Baumgartner et al., l.c.), then the previous age interpretations of the radiolarian limestones and radiolarites of the Western Carpathians must be revised.

The most striking difference in age assignment occurs for Zone A2 (middle Callovian - early Oxfordian), (Baumgartner, 1987), correlative with the UAZ.7 (late Bathonian - early Callovian). This older age assignment is the result of new Ammonite data from the Subbetic (Baumgartner et al., 1995).

### **Ždiarska vidla** (samples ŽV-2 and ŽV-8)

A radiolarian assemblage, in which the *Spumellaria* predominate, was encountered in the green-grey radiolarian limestones (sample ŽV-2). Biostratigrafically, they




comprise the species that cover a wide stratigraphic range (Text. Table) (UAZ.4, late Bajocian), such as the *Higumastra imbricata* (OŽVOLDOVÁ), *Homoeoparonaella argolidensis* BAUMGARTNER, *Paronaella broennimanni* PESSAGNO, *Triactoma blakei* (PESSAGNO), etc. that start to appear in the upper part of the Middle Jurassic period the highest position occupies the *Tritrabs ewingi worzeli* (PESSAGNO), in the UAZ.7, late Bathonian - early Callovian. The upper boundary of a possible occurrence of this association is determined by the *Higumastra imbricata* (OŽVOLDOVÁ), which occurrence of which terminates in UAZ.8, middle Callovian - early Oxfordian.

The radiolarian association in the green-grey radiolarites in the sample ŽV-8 is composed of similar genus and species and is predominated by the *Spumellaria* (Text. Table). The lower boundary is determined by the species *Archaeospongoprunum imlayi* PESSAGNO, which first appears in UAZ.7, late Bathonian - early Callovian. We assume that the upper boundary is in UAZ.8, in which the occurrence of species *Higumastra imbricata* (OŽVOLDOVÁ) and *Tricolocapsa plicarum* YAO terminates. In conclusion we may state that the sediments in the Ždiarska vidla section, represented by the samples ŽV-2 and ŽV-8 may have sedimented during the period between the Upper Bathonian and the Lower Oxfordian. Most probable is the late Bathonian - early Callovian age (UAZ.7), because UAZ.8, middle Callovian - early Oxfordian, is not represented by the new species characteristic for this zone, but instead, by fading-out of certain species.

**Banie Huciska**

The collected samples contained radiolarians and siliceous sponge spicules. Fairly numerous associations were extracted from the samples HC-5 and HC-8.

In the green-grey radiolarian limestones (HC-5) a little diversified radiolarian association, predominated by *Nasellaria*, was found. Of the determined species (Text. Table) of the lower part of the Middle Jurassic period, the *Stichocapsa convexa* YAO, (UAZ.1 — 11) and *Eucyrtidium unumaense* (YAO) (UAZ.3 — 8) appear. The *Tricolocapsa conexa* MATSUOKA first occurs in UAZ.4, late Bajocian, and terminate in UAZ.7, late Bathonian - early Callovian. Inasmuch as no such species were found in this association, which would determine a narrower time range, we can only conclude that the sedimentation took place sometimes between the Upper Bajocian and the Lower Callovian stages.

A radiolarian association, predominated by *Spumellaria*, was found in the green-grey radiolarian limestones (HC-8). Of the determined species (Text Table), the *Ho-*

*Text. tab. Occurrence of radiolarians in the sections*

| ***SPUMELLARIA NASSELLARIA*** | **UAZ** | **SECTIONS** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Genus species** | | **Ždiarska vidla** | | **Banie Huciska** | | **Gladkie Uplaziańskie** | | | |
| | | **ŽV-2** | **ŽV-8** | **HC-5** | **HC-8** | **GU-2** | **GU-3** | **GU-6** | **GU-10, 11** |
| *Acaeniotyle diaphorogona* FOREMAN | 4-22 | | + | | | | | | |
| *Acaeniotyle* sp. | | + | | | | | | | |
| *Acaeniotylopsis variatus* s.l. (OŽVOLDOVÁ) | 1-8 | | | | + | cf. | | | |
| *Acanthocircus trizonalis angustus* BAUMGARTNER | 6-10 | + | | | | | | | |
| *Alievum* sp. A | 8-9 | | | | | | | + | + |
| *Angulobracchia biordinalis* OŽVOLDOVÁ | 9-11 | | | | | | | | + |
| *Archaeospongoprunum imlayi* PESSAGNO | 7-12 | | + | | + | + | | + | + |
| *Archaeospongoprunum* sp. | | | | | | + | | | + |
| *Emiluvia chica* FOREMAN | 3-18 | | | | | + | | + | |
| *Emiluvia hopsoni* PESSAGNO | 6-15 | | | | | | | | + |
| *Emiluvia orea* BAUMGARTNER | 8-11 | | | | | | | + | |
| *Emiluvia pessagnoi* s.l. FOREMAN | 4-17 | | | | | + | | | |
| *Emiluvia premyogii* BAUMGARTNER | 3-10 | + | | | + | | | + | + |
| *Emiluvia salensis* PESSAGNO | 4-13 | | | | cf. | + | | + | + |
| *Emiluvia* sp. | | + | | | + | + | | + | |
| *Haliodictya hojnosi* RIEDEL et SANFILIPPO | 3-10 | | | | | | | | + |
| *Higumastra imbricata* (OŽVOLDOVÁ) | 4-8 | + | + | | + | | | | |
| *Higumastra wintereri* BAUMGARTNER | 1-8 | | | | | + | | | |
| *Homoeoparonaella* cf. *argolidensis* BAUMGARTNER | | + | + | | + | | | | |
| *Homoeoparonaella elegans* (PESSAGNO) | 4-10 | + | | | | | | | |
| *Homoeoparonaella gigantea* BAUMGARTNER | 8-10 | | | | + | | | | + |
| *Homoeoparonaella pseudoewingi* BAUMGARTNER | 3-7 | | | | + | | | | |
| *Monotrabs plenoides* BAUMGARTNER | 5-8 | | | | | + | + | | |
| *Orbiculiforma catenaria* OŽVOLDOVÁ | 7-9 | | | | | | | | + |
| *Orbiculiforma* sp. | | | | + | | | | | |
| *Paronaella broennimanni* PESSAGNO | 4-10 | cf. | cf. | | | + | | + | + |
| *Paronaella* cf. *kotura* BAUMGARTNER | 3-10 | + | | | | | | | |
| *Paronaella muelleri* PESSAGNO | 6-10 | | | | | + | cf. | + | |
| *Paronaella pristidentata* BAUMGARTNER | 10-11 | | | | | | | | + |
| *Paronaella* sp. | | | | | + | | | | + |
| *Tetraditryma corralitosensis bifida* CONTI et MARCUCCI | 5-7 | | | | | + | | | |
| *Tetraditryma pseudoplena* BAUMGARTNER | 4-11 | | | | | | | | + |
| *Tetratrabs bulbosa* BAUMGARTNER | 7-11 | | | | | | | + | |
| *Tetratrabs zealis* (OŽVOLDOVÁ) | 4-13 | | + | | + | + | | + | + |
| *Triactoma blakei* (PESSAGNO) | 4-11 | cf. | | | | | | + | |
| *Triactoma jonesi* (PESSAGNO) | 2-13 | + | | | + | | | | |
| *Triactoma mexicana* PESSAGNO et YANG | 5-9 | | | | + | | | | |
| *Triactoma parablakei* YANG et WANG | 4-7 | + | | | | + | | | |
| *Tripocyclia* cf. *trigonum* RÜST | | + | | | | | | + | |
| *Tritrabs casmaliaensis* (PESSAGNO) | 4-10 | | + | | | | | + | + |
| *Tritrabs exotica* (PESSAGNO) | 4-11 | cf. | | | + | | | + | |
| *Tritrabs ewingi* s.l. (PESSAGNO) | 4-22 | | + | | | | | | |
| *Tritrabs ewingi worzeli* (PESSAGNO) | 7-12 | + | | | + | | + | + | |
| *Tritrabs hayi* (PESSAGNO) | 3-10 | | | | + | | | | |
| *Tritrabs rhododactylus* BAUMGARTNER | 3-13 | | cf. | | | + | | + | + |
| *Archaeodictyomitra* sp. | | | | | + | | | | |
| *Dibolachras chandrica* KOCHER | 7-11 | | | | | cf. | | | + |
| *Eucyrtidiellum unumaense* s.l. (YAO) | 3-8 | | | + | | | | | |
| *Cinguloturris carpatica* DUMITRICĂ | 7-11 | | | | | | | + | |
| *Cinguloturris* sp. | | | | | | | | + | |
| *Mirifusus dianae* s.l. (KARRER) /section HC-10/ | 7-12 | | | | | | | | |
| *Napora lospensis* PESSAGNO | 8-13 | | | | | | | | + |
| *Obesacapsula morroensis* (PESSAGNO) | 5-21 | + | | | + | | | | |
| *Parahsuum* sp. | | | + | | | | | | |
| *Parvicingula dhimenaensis* ssp. A BAUMGARTNER | 3-8 | | | | | | | + | |
| *Parvicingula* sp. | | | | | | | | + | |
| *Perispyridium ordinarium* (PESSAGNO) | 5-11 | | | | + | + | | | |

| *SPUMELLARIA NASSELLARIA* | UAZ | SECTIONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Genus species | | Ždiarska vidla | | Banie Huciska | | Gladkie Uplaziańske | | | |
| | | ŽV-2 | ŽV-8 | HC-5 | HC-8 | GU-2 | GU-3 | GU-6 | GU-10, 11 |
| *Perispyridium* cf. *tamanense* PESSAGNO et BLOME | | | | | | | | | + |
| *Podobursa helvetica* (RÜST) | 3-10 | | cf. | | cf. | + | | | |
| *Podobursa polyacantha* (FISCHLI) | 5-8 | | | | | | | + | |
| *Podobursa quadriaculeata* (STEIGER) | 9-17 | | | | | | | | + |
| *Podobursa triacantha* (FISCHLI) | 5-8 | cf. | | | + | | | | + |
| *Poliandromeda podbielensis* (OŽVOLDOVÁ) | 1-7 | | | | | | + | | |
| *Ristola procera* (PESSAGNO) | 5-9 | | + | | | | | | |
| *Sethocapsa sphaerica* (OŽVOLDOVÁ) | 9-11 | | | | | | | | + |
| *Sethocapsa* sp. 1 | | | | | | | | | + |
| *Sethocapsa* sp. 2 | | | | | | | | | + |
| *Spongocapsula perampla* (RÜST) | 6-11 | | | | | | | + | |
| *Stichocapsa convexa* YAO | 1-11 | | | + | | | | | |
| *Transhsuum brevicostatum* (OŽVOLDOVÁ) | 3-11 | cf. | + | | + | | + | + | + |
| *Transhsuum maxwelli* (PESSAGNO) | 3-10 | | | | | cf. | + | | |
| *Transhsuum* cf. *okamurai* (MIZUTANI) | | | | | + | | | | |
| *Tricolocapsa conexa* MATSUOKA | 4-7 | | | + | | | | | |
| *Tricolocapsa plicarum* s.l. YAO | 3-8 | | + | + | | | | | |
| *Tricolocapsa* cf. *yaoi* MATSUOKA | | | + | | | | | | |
| *Tricolocapsa* sp. | | | + | | | | | + | |
| *Xitus* sp. | | | | | | | | + | |

*moeoparonaella gigantea* BAUMGARTNER, which first appears in UAZ.8, middle Callovian - early Oxfordian, as well as the fading-out species, such as the *Acaeniotylopsis variatus* (OŽVOLDOVÁ) and *Higumastra imbricata* (OŽVOLDOVÁ), are important. The absence in this zone of the other important species is questionable. From the above it follows that for the sediments represented by the sample HC-8, a Middle Callovian to Lower Oxfordian age may be assumed.

In the red radiolarian limestones (HC-10) only three pieces of *Nassellaria* genus were encountered. The only determinable species is *Mirifusus dianae* (KARRER), which has a wide range of occurrence in the UAZ.7 — 12, thus, their age ranges from the Upper Bajocian to the Upper Tithonian.

No radiolarians were found in the overlying, slab-like, black spongolites (HC-11). However, they do contain abundant of siliceous sponge spicules.

**Gladkie Uplaziańskie**

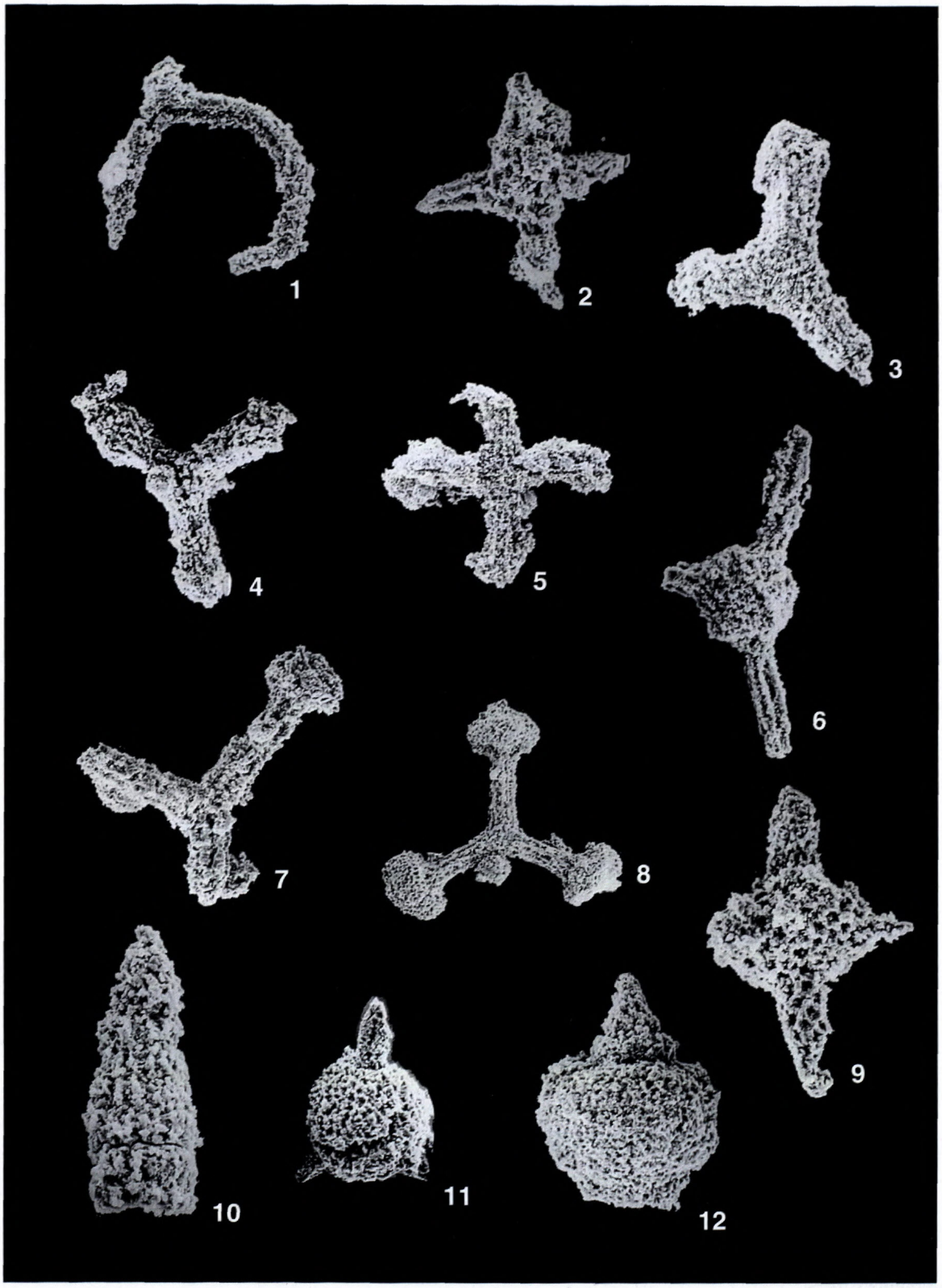
11 samples were collected from this section, in which the radiolarians of various abundances and degree of preservation were found. The richest samples GU-2, GU-6, and GU-10 were evaluated.

Quite poorly preserved radiolarian tests, most of them *Spumellaria,* were found in the green-grey radiolarites (samples GU-2 and GU-3). Most evaluated species (Text Table) first appear in the upper part of the Middle Jurassic. In UAZ.7, which corresponds to the late Bathonian - early Callovian, there appear *Dibolachtras chandrica* KOCHER, *Archaeospongoprunum imlayi* PESSAGNO and *Tritrabs ewingi worzeli* (PESSAGNO). In turn, the species *Tetraditryma corralitosensis bifida* CONTI et MARCUCCI and *Triactoma parablakei* YANG et WANG occurrence of which terminate in this zone. We assume that this time span (late Bathonian to early Callovian) corresponds to the period of sedimentation of the rocks represented by the samples GU-2 and GU-3.

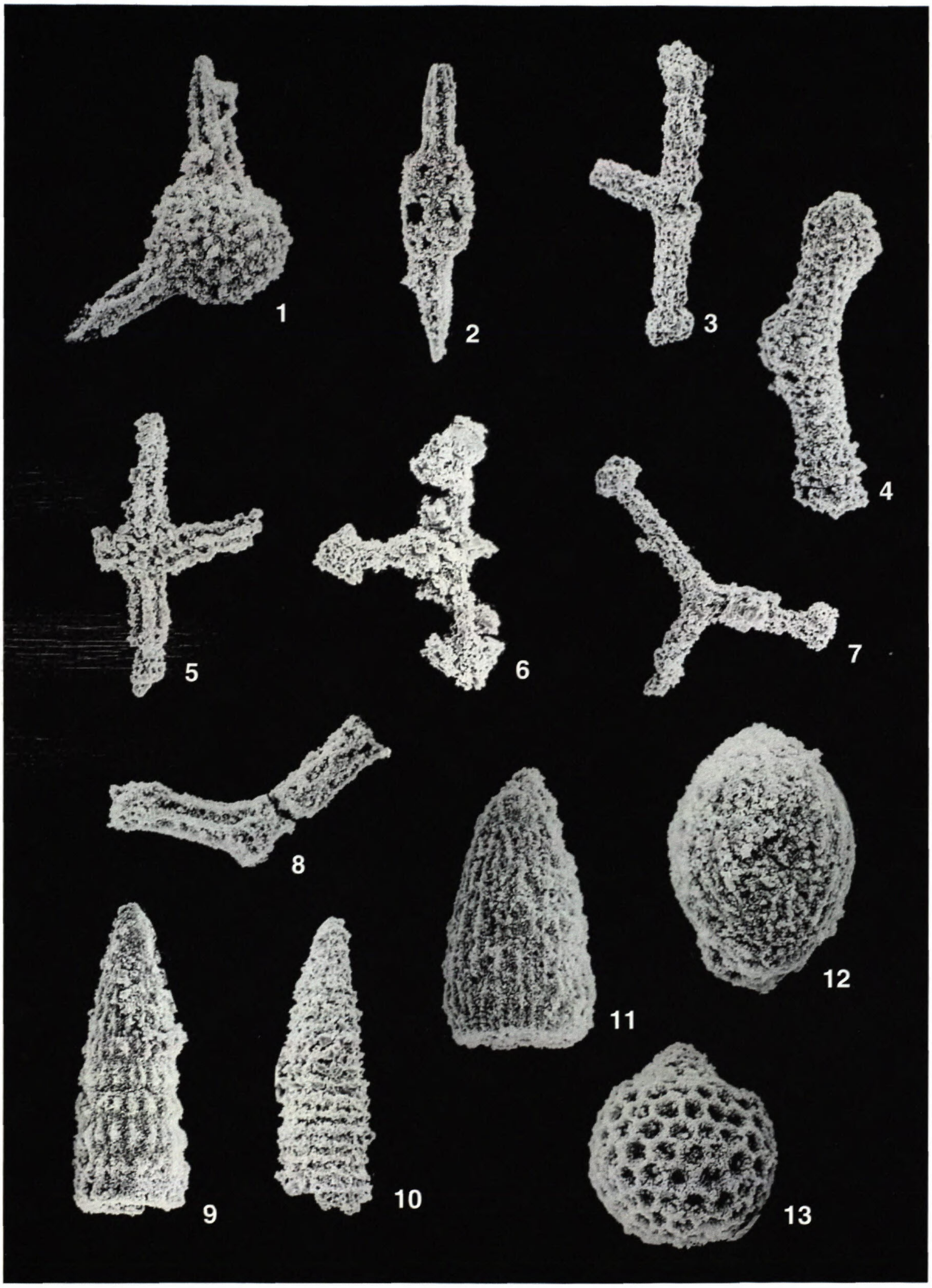
In the green-grey radiolarites (sample GU-6) a more varied and better preserved radiolarian association, predominated by *Spumellaria,* was found. To assign an age to a certain zone, it must contain the species and they first and final occurrence. In UAZ.8 (middle Callovian - early Oxfordian) the species: *Parvicingula dhimenensis* BAUMGARTNER, *Podobrusa polyacantha* (FISCHLI) and *Tetratrabs zealis* (OŽVOLDOVÁ) terminate while the species *Alievum* sp. A (BAUMGARTNER et al., 1995) and *Emiluvia orea* BAUMGARTNER. *Emiluvia ordinaria* OŽVOLDOVÁ appear. We presume that the radiolarian assemblage in the sample GU-6 represents UAZ.8, middle Callovian - early Oxfordian, which, corresponds to the assumed age of the sediments under study.

In the grey and red radiolarites (samples GU-10 and GU-11), the radiolarian associations, predominated by *Spumellaria,* were found. Among them, the species that first appear in the Middle Oxfordian (UAZ.9 middle and late Oxfordian), such as the *Sethocapsa sphaerica* (OŽVOLDOVÁ), *Angulobracchia biordinalis* OŽVOLDOVÁ and the *Podobursa quadriaculeata* (STEIGER). In UAZ.10 (late Oxfordian - early Kimmeridgian) the species *Emiluvia premyogii* BAUGARTNER, *Haliodictya hojnosi* RIEDEL et SANFILIPPO, *Paronaella broennimann* PESSAGNO and *Tritrabs casmaliaensis* (PESSAGNO) and they first and final occurrence.

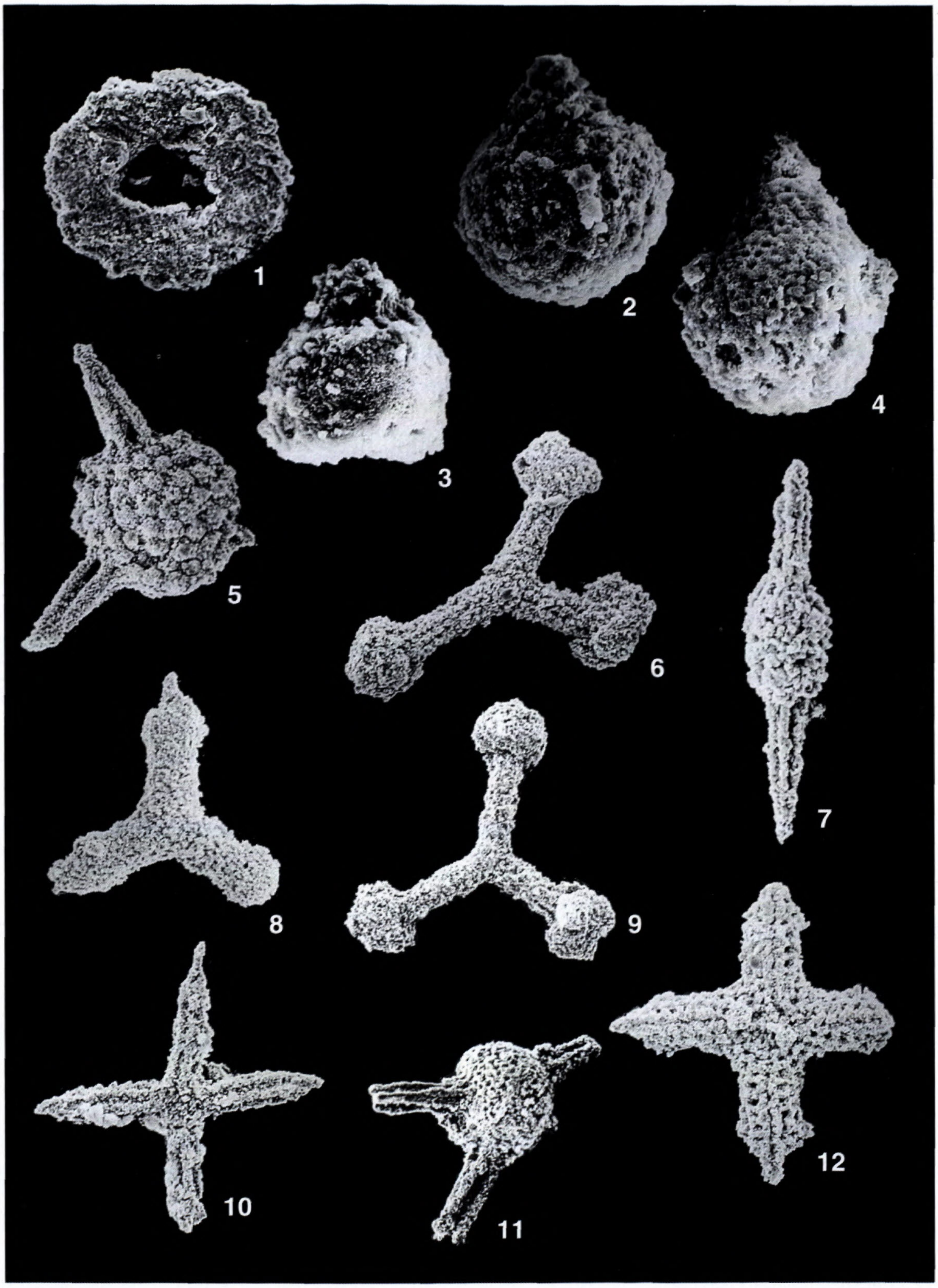
However, the *Paronaella pristidentata* BAUMGARTNER appears in this zone. We assume that the associations under studiy represent UAZ.10.- late Oxfordian - early Kimmeridgian.




**Pl. 1. Ždiarska vidla.**
**Sample ŽV-2, Figs. 1 - 12:**
1 - *Acanthocircus trizonalis angustus* BAUMGARTNER - 4789, 120 x, 2 - *Emiluvia premyogii* BAUMGARTNER - 4798, 110 x, 3 - *Paronaella* cf. *broennimanni* PESSAGNO - 4864, 150 x, 4 - *Homoeoparonaella elegans* (PESSAGNO) - 4797, 120 x, 5 - *Higumastra imbricata* (OŽVOLDOVÁ) - 4802, 70 x, 6 - *Triactoma jonesi* (PESSAGNO) - 4800, 110 x, 7 - *Tritrabs ewingi worzeli* (PESSAGNO) - 4801, 90 x, 8 - *Tritrabs ewingi worzeli* (PESSAGNO) - 4786, 60 x, 9 - *Podobursa* cf. *triacantha* (FISCHLI) - 4794, 150 x, 10 - *Transhsuum* cf. *brevicostatum* (OŽVOLDOVÁ) - 4811, 170 x, 11 - *Triactoma* cf. *blakei* (PESSAGNO) - 4807, 100 x, 12 - *Obesacapsula morroensis* (PESSAGNO) - 4805, 90 x.




**Pl. 2. Ždiarska vidla.**
**Sample ŽV-8, Figs. 1 - 13:**
1 - *Acaeniotyle diaphorogona* FOREMAN - 4862, 210 x, 2 - *Archaeospongoprunum imlayi* PESSAGNO - 4865, 140 x, 3 - *Homoeoparonaella* cf. *argolidensis* BAUMGARTNER - 4871, 90 x, 4 - *Paronaella* cf. *broennimanni* PESSAGNO - 4874, 130 x, 5 - *Tetratrabs zealis* (OŽVOLDOVÁ) - 4888, 100 x, 6 - *Higumastra imbricata* (OŽVOLDOVÁ) - 4880, 80 x, 7 - *Tritrabs ewingi* s.l. (PESSAGNO) - 4870, 80 x, 8 - *Tritrabs casmaliaensis* (PESSAGNO) - 4867, 150 x, 9 - *Transhsuum brevicostatum* (OŽVOLDOVÁ) - 4873, 175 x, 10 - *Ristola procera* (PESSAGNO) - 4879, 110 x, 11 - *Parahsuum* sp. - 4872, 185 x, 12 - *Tricolocapsa* cf. *plicarum* YAO - 4875, 300 x, 13 - *Tricolocapsa* sp. - 4885, 300 x.



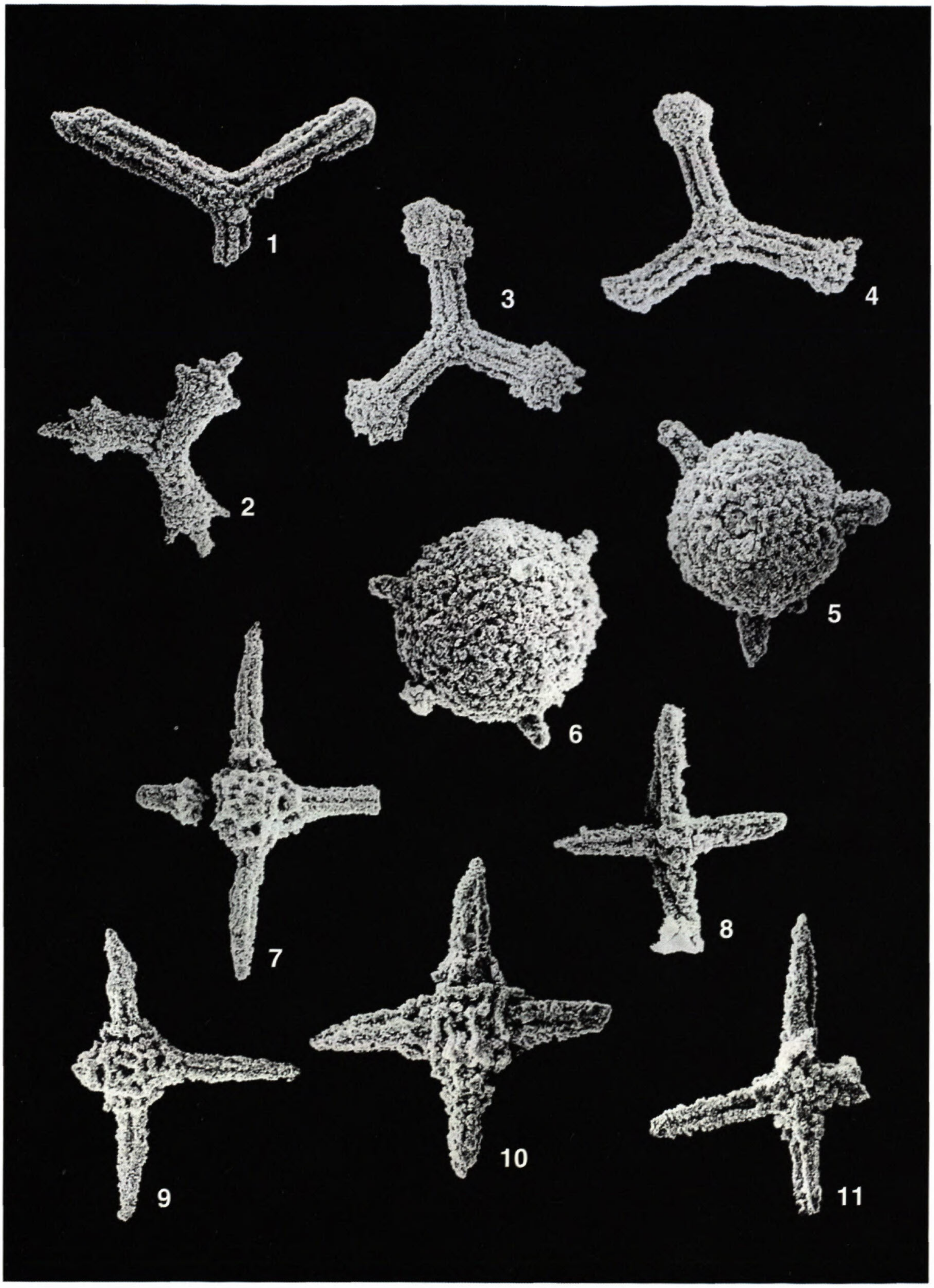

**Pl. 3. Banie Huciska.**

**Sample HC-5, Figs. 1 - 4:**

1 - *Orbiculiforma* sp. - 0043, 145 x, 2 - *Tricolocapsa conexa* MATSUOKA - 0045, 300 x, 3 - *Eucyrtidiellum unumaense* s.l. (YAO) - 1075, 400 x, 4 - *Stichocapsa convexa* YAO - 0046, 300 x.

**Sample HC-8, Figs. 5 - 12:**

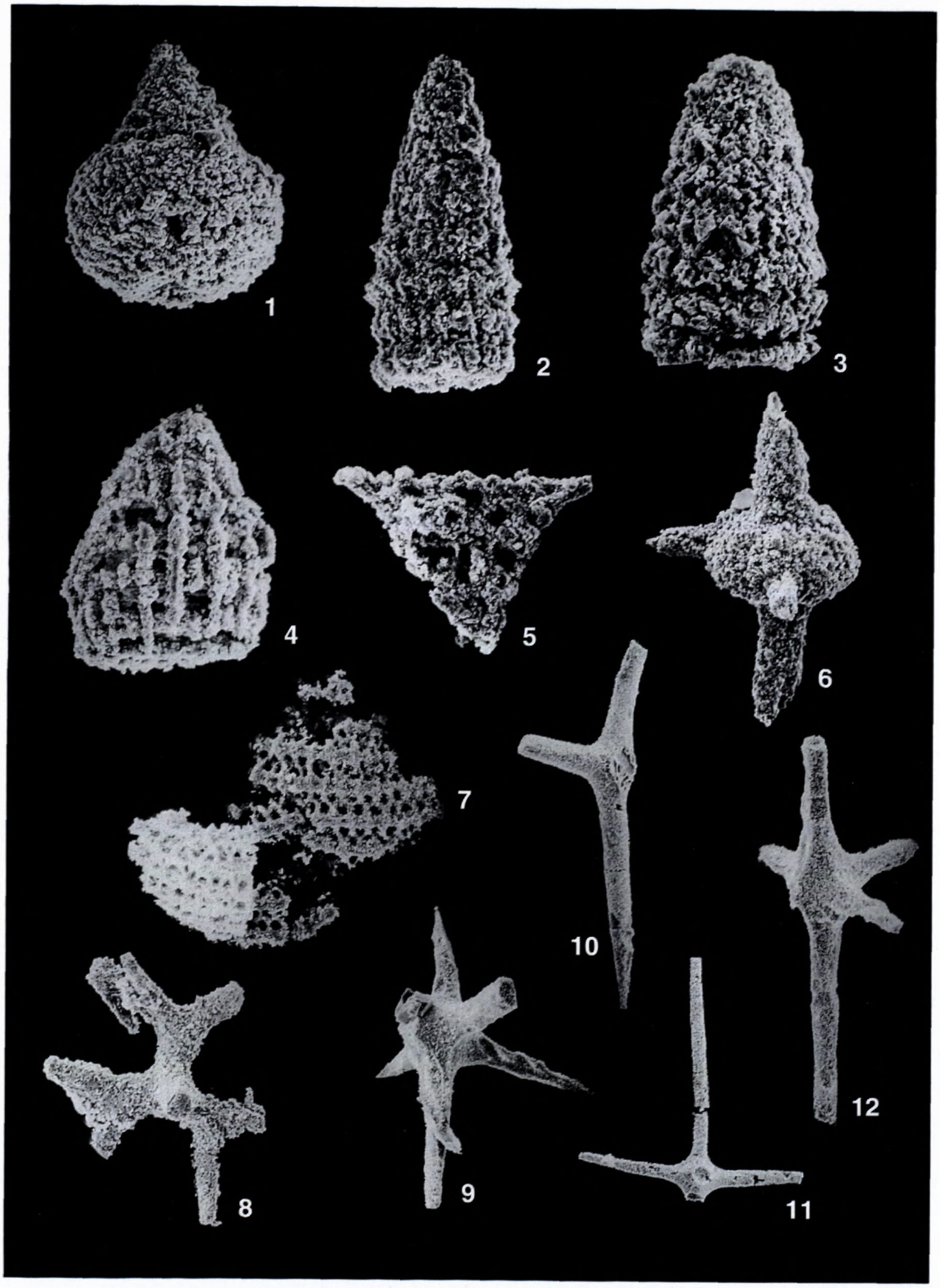
5 - *Acaeniotylopsis variatus* s. l. (OŽVOLDOVÁ) - 1035, 110 x, 6 - *Homoeoparonaella* cf. *argolidensis* BAUMGARTNER - 1041, 100 x, 7 - *Archaeospongoprunum imlayi* PESSAGNO - 1030, 165 x, 8 - *Homoeoparonaella gigantea* BAUMGRARTNER - 1027, 100 x, 9 - ?*Homoeoparonaella pseudoewingi* BAUMGARTNER - 1059, 75 x, 10 - *Tetratrabs zealis* (OŽVOLDOVÁ) - 1033, 80 x, 11 - *Triactoma jonesi* (PESSAGNO) - 10044, 100 x, 12 - *Higumastra imbricata* (OŽVOLDOVÁ) - 1026, 100 x.




**Pl. 4. Banie Huciska.**

**Sample HC-8, Figs. 1 - 11:**

1 - *Tritrabs hayi* (PESSAGNO) - 1066, 90 x, 2 - *?Paronaella* sp. - 1051, 90 x, 3 - *Tritrabs exotica* (PESSAGNO) - 1039, 115 x, 4 - *Tritrabs exotica* (PESSAGNO) - 1036, 80 x, 5 - *Triactoma mexicana* PESSAGNO et YANG - 1037, 130 x, 6 - *Triactoma mexicana* PESSAGNO et YANG - 1043, 110 x, 7 - *Emiluvia* sp. - 1031, 100 x, 8 - *Emiluvia* sp. - 1038, 115 x, 9 - *Emiluvia chica* s.l. FOREMAN - 1058, 85 x, 10 - *Emiluvia premyogii* BAUMGARTNER - 1067, 130 x, 11 - *Emiluvia* cf. *salensis* PESSAGNO - 1071, 110 x



**Pl. 5. Banie Huciska.**

**Sample HC-8, Figs. 1 - 6:**

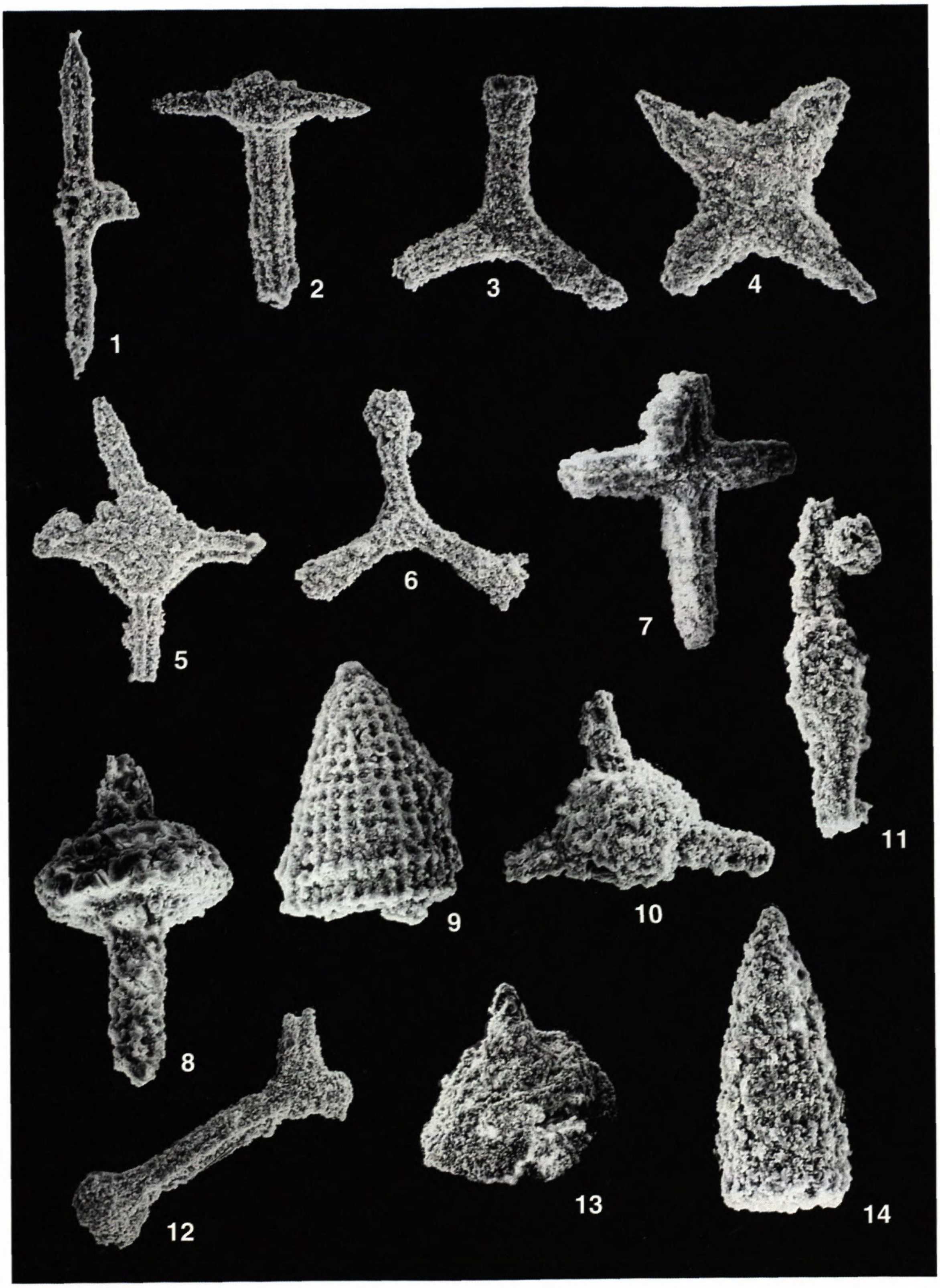
1 - *Obesacapsula morroensis* (PESSAGNO) - 1034, 115 x, 2 - *Transhsuum brevicostatum* (OŽVOLDOVÁ) - 1054, 185 x, 3 - *Transhsuum* cf. *okamurai* (MIZUTANI) - 1048, 225 x, 4 - *Archaeodictyomitra* sp. - 1028, 200 x, 5 - *Perispyridium ordinarium* (PESSAGNO) - 1047, 160 x, 6 - *Podobursa triacantha* s.l. (FISCHLI) - 1057, 120 x.

**Sample HC-10, Fig. 7:**

7 - *Mirifusus dianae* s.l. (KARRER) - 1082, 160 x.

**Sample HC-11, Figs. 8 - 12:**

8 - 12 - *Sponge spicules*: 8 - 1085, 70 x; 9 - 1089, 115 x; 10 - 1087, 90 x; 11 - 1088, 70 x; 12 - 1084, 105 x.



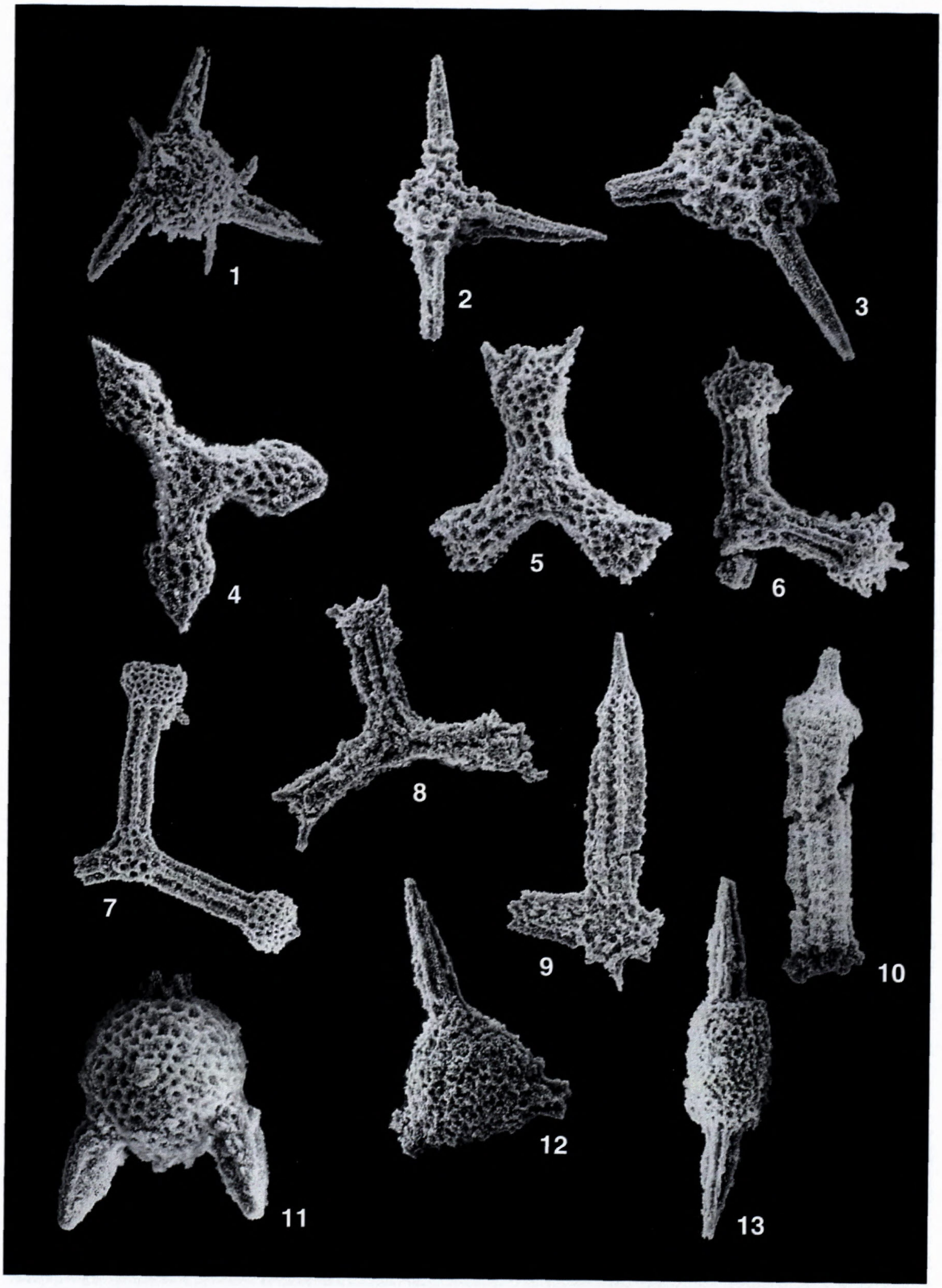

**Pl. 6. Gladkie Uplaziańskie.**

**Sample GU-2, Figs. 1 - 11:**

1 - *Tetraditryma corralitosensis bifida* CONTI et MARCUCCI - 1381, 110 x, 2 - *Monotrabs plenoides* gr. BAUMGARTNER - 1393, 120 x, 3 - *Paronaella* cf. *broennimanni* PESSAGNO - 1367, 100 x, 4 - *Pseudocrucella* cf. *sanfilippoae* (PESSAGNO) - 1373, 140 x, 5 - *Emiluvia pessagnoi* s.l. FOREMAN - 1364, 120 x, 6 - *Tritrabs rhododactylus* BAUMGARTNER - 1371, 110 x, 7 - *Tetratrabs zealis* (OŽVOLDOVÁ) - 1376, 120 x, 8 - *Podobursa helvetica* (RÜST) - 1391, 120 x, 9 - *Parahsuum* sp. - 1370, 190 x, 10 - *Triactoma parablakei* YANG et WANG - 1388, 170 x, 11 - *Archaeospongoprunum imlayi* PESSAGNO - 1372, 140 x.

**Sample GU-3, Figs. 12 - 14:**

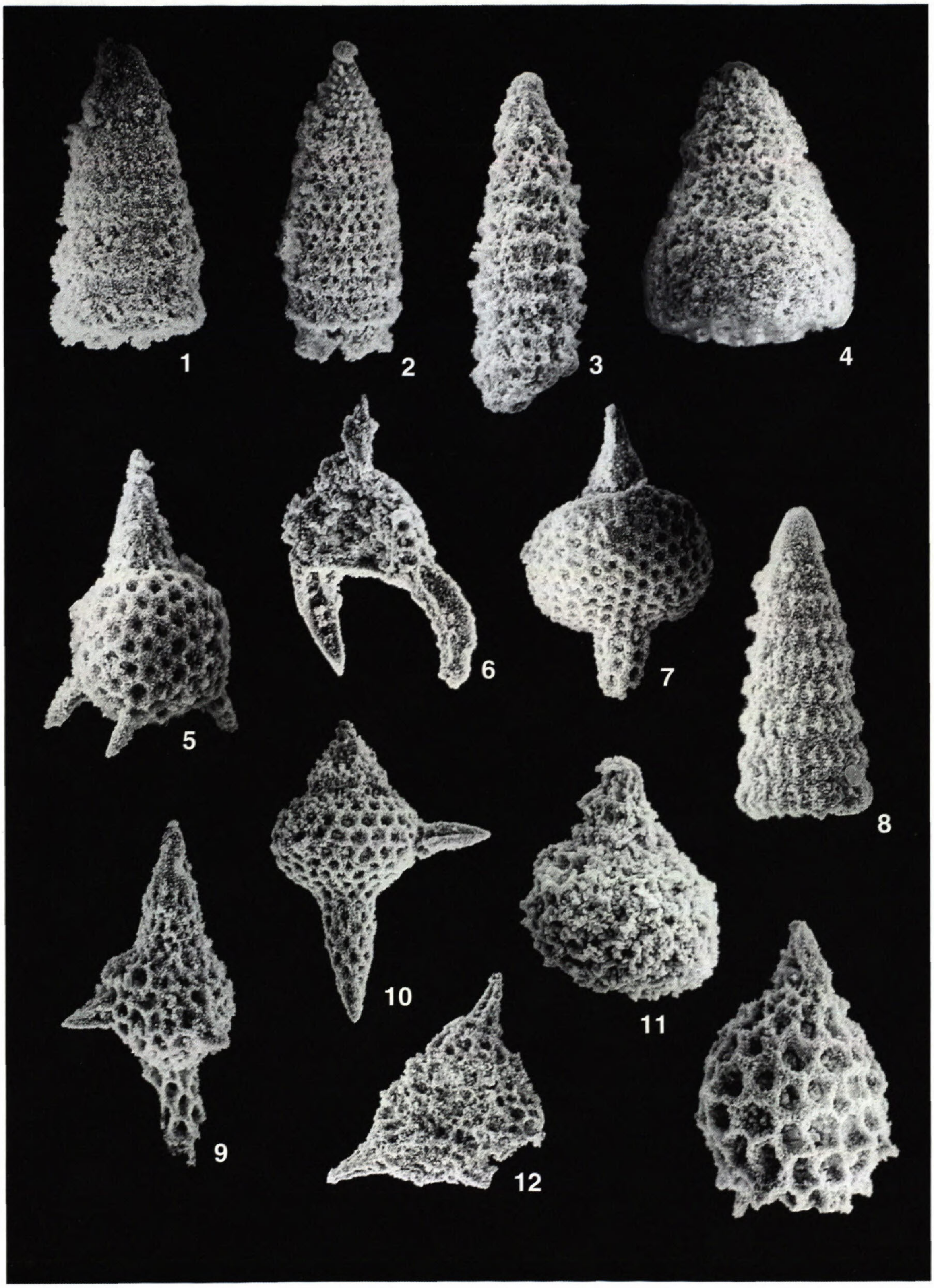
12 - *Tritrabs ewingi worzeli* (PESSAGNO) - 1445, 90 x, 13 - *Poliandromeda podbielensis* (OŽVOLDOVÁ) - 1447, 100 x, 14 - *Transhsuum* cf. *maxwelli* (PESSAGNO)- 1454, 200 x.




**Pl. 7. Gladkie Uplaziańskie.**

**Sample GU-6, Figs. 1 - 13:**

1 - *Alievum* sp. A - 1395, 140 x, 2 - *Emiluvia salensis* PESSAGNO - 1346, 120 x, 3 - *Emiluvia orea* BAUMGARTNER - 1402, 150 x, 4 - *Paronaella muelleri* PESSAGNO - 1349, 170 x, 5 - *Paronaella* sp. - 1358, 170 x; 1397, 120 x, 6 - *Tritrabs exotica* (PESSAGNO) - 1397, 120 x, 7 - *Tritrabs ewingi worzeli* (PESSAGNO) - 1332, 90 x, 8 - *Tritrabs casmaliaensis* (PESSAGNO) - 1403, 120 x, 9 - *Tetratrabs zealis* (OŽVOLDOVÁ) - 1335, 100 x, 10 - *Tetratrabs bulbosa* BAUMGARTNER - 1341, 120 x, 11 - *Triactoma blakei* (PESSAGNO) - 1334, 155 x, 12 - *Tripocyclia* cf. *trigonum* RÜST - 1519, 160 x, 13 - *Archaeospongoprunum imlayi* PESSAGNO - 1337, 150 x.



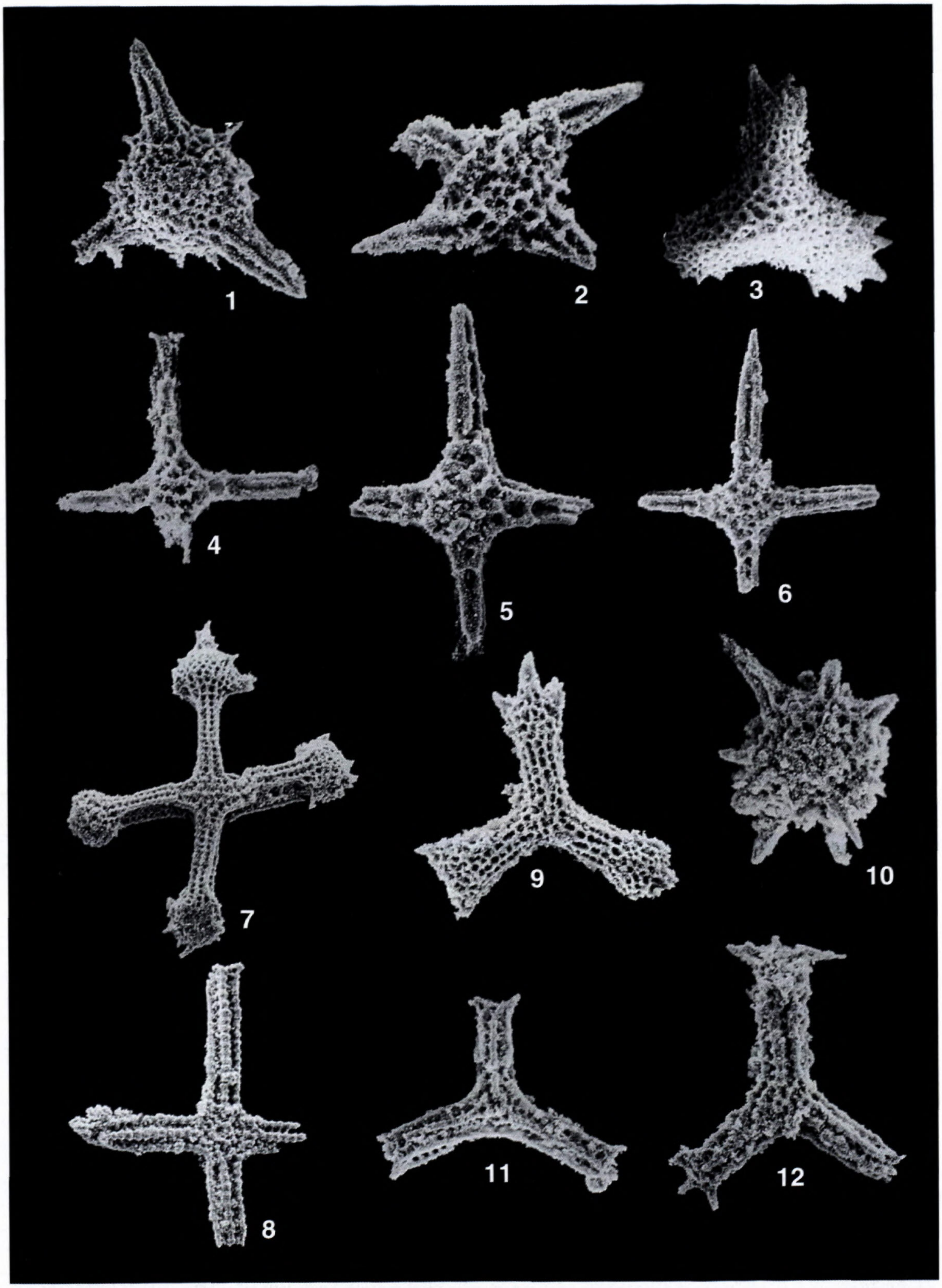

**Pl. 8. Gladkie Uplaziańskie.**

**Sample GU-6, Figs. 1 - 4:**

1 - *Cinguloturris carpatica* DUMITRICĂ - 1429, 260 x, 2 - *Parvicingula* sp. - 1339, 230 x, 2 - *Parvicingula dhimenaensis* ssp. A BAUMGARTNER - 1344, 210 x, 4 - *Spongocapsula perampla* (RÜST) - 1338, 170 x.

**Sample GU-10, Figs. 5 - 13:**

5 - *Sethocapsa sphaerica* (OŽVOLDOVÁ) - 1406, 220 x, 6 - *Napora lospensis* PESSAGNO - 1409, 100 x, 7 - *Dibolachras chandrica* KOCHER - 1441, 125 x, 8 - *Transhsuum brevicostatum* (OŽVOLDOVÁ) - 1412, 170 x, 9 - *Podobursa quadriaculeata* (STEIGER) - 1440, 190 x, 10 - *Podobursa triacantha* (FISCHLI) - 1416, 160 x, 11 - *Sethocapsa* sp. 1 - 1433, 200 x, 12 - *Perispyridium* cf. *tamanense* PESSAGNO et BLOME - 1432, 120 x, 13 - *Sethocapsa* sp. 2 - 1428, 250 x.




**Pl. 9. Gladkie Uplaziańskie.**

**Sample GU-10, Figs. 1 - 12:**

1 - *Alievum* sp. A - 1420, 160 x, 2 - *Haliodictya hojnosi* RIEDEL et SANFILIPPO - 1339, 230 x, 3 - *Paronaella pristidentata* BAUMGARTNER - 1424, 125 x, 4 - *Emiluvia hopsoni* PESSAGNO - 1443, 130 x, 5 - *Emiluvia salensis* PESSAGNO - 1419, 150 x, 6 - *Emiluvia salensis* PESSAGNO - 1438, 120 x, 7 - *Tetraditryma pseudoplena* BAUMGARTNER - 1414, 90 x, 8 - *Tetratrabs zealis* (OŽVOLDOVÁ) - 1417, 80 x, 9 - *Paronaella* sp. - 1426, 130 x, 10 - Gen. et sp. indet. - 1413, 170 x, 11 - *Tritrabs casmaliaensis* (PESSAGNO) - 1360, 130 x, 12 - *Tritrabs casmaliaensis* (PESSAGNO) - 1442, 140 x.

## Discussion

The Middle to Upper Jurassic radiolarian limestones and radiolarite sequences in the Pieniny section of the Klippen belt were classified by Birkenmajer (1977) as the lower radiolarites of the Sokolica formation, which the author assigned to the Bathonian - Callovian stages, while the upper radiolarites of the Czajakowa he assigns to the Oxfordian - Kimmeridgian stages. Stratigraphically, the same view held Lefeld et al. (1985) and Lefeld (1988).

However, our correlation of the stratigraphic position of radiolarian asociations of the Middle - Upper Jurassic sequences of the Krížna nappe in almost all Western Carpathian core mountains has shown that it does not comply with the Lefeld`s (1988) classification of radiolarites of the Krížna nappe, which he divided into lower (predominantly green), correlable with the Sokolica radiolarites and the upper (predominantly red) analogous to the Czajakowa radiolarites. Having evaluated the samples from almost 20 compete sections through the Middle and Upper Jurassic radiolarian limestones and radiolarites we can conclude that there exists no objective and exact reason for dividing this formation in two. Thus, we consider it necessary to define a new lithostratigraphic unit - **the Ždiar Formation** - comprising the Upper Bathonian - Lower Kimmeridgian assemblage of the radiolarian limestones and radiolarites of the Krížna nappe.

The results of analyses of the Western Carpathian, Krížna nappe, Źdiar Formation sediments show that their origin is bound to the onset of the post-riftogenic process, which that took place in a typically basinal environment of the Tethyan passive margin.

## Conclusion

The presented contribution supplements and extends the knowledge of radiolarian limestones and radiolarites in another Western Carpathian core mountains - the Tatry Mts..

A new lithostratigraphic unit - the **Ždiar Formation** was determined and characterized.

The stratigraphic range of the Ždiar Formation was assessed on the basis of radiolarian microfauna, which represents the zones UAZ.7, UAZ.8, UAZ.9 and UAZ.10 of BAUMGARTNER et al. (1995). In conclusion we can state that the age of the Ždiar Formation corresponds to the Upper Bathonian - Lower Kimmeridgian.

## References

Baumgartner, P. O., 1984: A Middle Jurassic - Early Cretaceous low latitude radiolarian zonation based on Unitary Associations and age of Tethyan radiolarites. *Eclogae geol. Helv.* (Basel), 77, 3, 729-827.

Baumgartner, P. O., 1987: Age and genesis of Tethyan Jurassic Radiolarites. *Eclogae geol. Helv.* (Basel), 80, 3, 831-879.

Baumgartner, P. O., O'Dogherty, L., Goričan, S., Urquhart, E., Pillevuit, A. & De Wever, P., 1995: Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurences, Systematics, Biochronology. Mémoires de Géologie (Lausanne), 23 (Section des Sciences de la Terre Institut de Géologie et Paléontologie Université de Lausanne), 1172.

Birkenmajer, K., 1977: Jurassic and Cretaceous lithostratigraphic Units of the Pieniny Klippen Belt Carpathians Poland. *Stud. geol. pol.* (Warszawa), 45, 1-158.

Gaździcki, A., Michalík, J., Planderová, E. & Sýkora, M., 1979: An Upper Triassic - Lower Jurassic sequence in the Krížna Nappe (West Tatra Mts., West Carpathians, Czechoslovakia). *Západ. Karpaty, Sér. Geol.* (Bratislava), 5, 119-148.

Krajewski, R. & Myszka, J., 1958: Wapienie manganowe w Tatrach między Doliną Chochołowską a Lejową / Manganiferous limestones in the Tatra Mts between the Chochołowska and Lejowa Valleys. *Biuletyn* /Inst. geol./ (Warszawa), 126, 209-300.

Lefeld, J., 1974: Middle-Upper Jurassic and Lower Cretaceous biostratigraphy and sedimentology of the Sub-Tatric Succession in the Tatra Mts (Western Carpathians). *Acta geol. pol.* (Warszawa), 24, 2, 277-364.

Lefeld, J., 1981: Upper Jurassic radiolarite-nodular limestone vertical symmetry in the Polish Central Carpathians as reflection of regional depth changes in the ocean. *Stud. geol. pol.* (Warszawa), 68, 89-96.

Lefeld, J., 1988: Radiolarites and Associated Rocks along the Northern Margin of Tethys. In Evolution of the Northern Margin of Tethys: The Results of IGCP Project 198, vol. 1, 147-164, 24 obr., 3 tab.

Lefeld, J. (Editor), Gaździcki, A., Iwanow, A., Krajewski, K. & Wójcik, K., 1985: Jurassic and Cretaceous lithostratigraphic units of the Tatra Mountains / Jurajskie i kredowe jednostki litostratygraficzne *Tatr. Stud. geol. pol.* (Warszawa), 84,

O'Dogherty, L., Sandoval, J., Martin-Algara, A. & Baumgartner, P. O. 1989: Las facies con radiolarios del Jurassic Subbetico (Cordillera Betica, sur de España). *Rev. Soc. Mex. Paleont.*, 2, 1, 70-77.

Polák, M. & Ondrejičková, A., 1993a: Litostratigrafia rádioláriových vápencov a rádiolaritov krížňanského príkrovu Strážovských vrchov. In Rakús, M. & Vozár, J. (Editors), 1993: Geodynamický model a hlbinná stavba Západných Karpát. Zborník referátov zo seminára (17.-18.12.1992), Geol. Úst. D. Štúra, Bratislava, 95-101.

Polák, M. & Ondrejičková, A., 1993b: Lithology, microfacies and biostratigraphy of radiolarian limestones, radiolarites in the Krížna nappe of the Western Carpathians. *Miner. slov.* (Bratislava), 25, 6, 391-410.

Polák, M. & Ondrejičková, A., 1995: Lithostratigraphy of Radiolarian Limestones and Radiolarites of the Envelope Sequence in the Veľká Fatra Mts. *Slovak Geol. Mag.* (Bratislava), 2, 153-158.

Rabowski, F. & Goetel, W., 1925: Budowa Tatr. Pasmo reglowe / Les nappes de récouvrement de la Tatra. La structure de la zone subtatrique. *Spraw. Pol. Inst. geol.* (Warszawa), 3, 1-2.

Schläger, W. & Schläger, M., 1969: Über die Sedimentationsbedingungen der jurassischen Tauglbodenschichten (Osternhorngruppe, Salzburg). *Anz. Österr. Akad. Wiss., Math. Naturwiss.* (Wien), K 1, 10, 178-183.

Sokolowski, S., 1925: Spostrzeżenia nad wiekiem i wykształceniem liasu reglowego w Tatrach / Beobachtungen über das Alter und die Entwicklung des subtatrischen Lias im Tatragebirge. Rocz. Pol. Tow. geol. /*Ann. Soc. Géol. Pol.*/, (Kraków), 2, 78-84.

Sujkowski, Z., 1932: Radiolaryty Polskich Karpat Wschodnich i cih porównanie z radiolarytami tatrzańskimi / Radilarites des Karpathes Polonaises Orientales et leur comparaison avec les radiolarites de la Tatra. *Spraw. Państw. Inst. Geol.* (Warszawa), 7, 1, 97-168.

Walker, R. G., 1967: Turbidite sedimentary structures and their relationships to proximal and distal depositional enviroments. *J. sed. Petrology* (Tulsa), 37, 25-43.

# Exploitation and use of brown coal from the Nováky deposit and ist environmental impact

[1]PETER ŠEFČÍK and FRANTIŠEK PETRIK [2]

[1] Soil Fertility Research Institute, Bratislava
[2] Department of Mining Geology Faculty of Sciences Comenius University, Bratislava

***Abstract:*** The Nováky brown coal deposit is located in the Handlová-nováky coal basin. The basin is located in Central Slovakia and it is within the intramountainous basins of Western Carpathians. The Nováky deposit is most significant brown - coal resource in Slovakia. The Nováky coal bed contains the following coal lithotypes listed in order of importance: detritic, xylitic-detritic, xylitic, detritic-xylitic and mother of coal. Most dominate maceral group in the deposit is huminitic, represented with humotelinite, humodetrinite and humokolinite. Other maceral groups identified in the bed liptinite (kutinite, suberinite, rezinite) and inertinite (inertodetrinite, fuzinite and sklerotinite). With respect carbonization the Nováky coal bed is included in the brown-coal stage of the change with medium vitrinite reflectance ( $R_0 = 0.275\%$). The mean caloricity value of the Nováky coals is 12.08 MJ.

The mineralization Nováky coal bed consists of clays, tuffs, quartz various forms, sulphides of iron and arsenic, and dolomite. Iron sulphides (pyrite, marcasite) commonly occur in the form of micronodules. Arsenic sulphides (realgar and auripigment) occur at discontinuity areas (layered areas, dilatation cracks, dislocations) and are related to the Vtáčnik volcanic activity.

The Hornonitrianske bane š.p. (Mines of Upper Nitra), at present, are producing approximately 2.8 million tons of coal and lignite. The Baňa Cígeľ production is 29%, Baňa Handlová 31% and Baňa Nováky 40% of the total respectively. The Cígeľ and Handlová mines produce brown coal, and Nováky mine lignite. All coal production has been used for power generation and chemical processing.

The Nováky coal can be chracterized by the following facts: 1. highest caloricity value in main coal seam was found in its central part; 2. rocks sulphur contents were shown to increase with depth; 3. sulphur contents in volcano-sedimentary rocks are nearly half, when compared with coal; 4. As contents, when compare to sulphur, decrease with depth; 5. contents of other harmful elements, F and Cl, in coal and in overburden are approximately the same and do not show significant changes with depth; 6. Fe contents in volcanosedimentary rocks are approximately double when compared to the coal and in coal and overburden there is increase with depth ; 7. in lateral element distribution, to As, S, Fe decrease to the north of deposit; 8. F contents in the deposit are more or less homogenous and Cl levels show moderate tendency to increase towards the centre; 9. increased S content in the seat rock, in part can be results from the gypsum concentration, its occurrence increases in the seat rock.

***Key words*:** coal basin, coal deposit, coal bed, maceral group, vitrinite reflectance, coal geochemistry, coal bed mineralization, element distribution, soil types, geochemical mapping

## Introduction

Handlovsko-novácka basin (the coal basin of Handlovská-Nováky) is located in the Horná Nitra (Upper Nitra) region. From the hydrological view the region belongs to Nitra River catchment basin, and most significant tributary is Handlovka River. Near city of Prievidza, there is thermal spa, Bojnice, of national significance. The Horná Nitra Region is highly industrialized, dominant industries are mining, power generation and chemical production, respectively. Long-term industrial activities of the region caused environment deterioration of the soils, water and atmosphere. Therefore the Upper Nitra region was included in Slovakia environmental policies that included "hot spot regions" with emphases on immediate landscape revitalisation.

## Geology of the Handlová-Nováky coal basin

Nováky brown coal of is in the Handlová-nováky coal basin. The basin is located in central Slovakia in the intramountainous basins of Western Carpathians. The Nováky deposit is most significant brown- coal resource in Slovakia.

The basin basement rocks consists of crystalline rocks of Choč and Krížna nappies and melaphyre series. This is overlain by sedimentary rocks of the Subtatra Group of Central Carpathian paleogene. The sedimentary rocks consists of mudstone, flysch and sandstone. The upper Paleogene is missing due to denudation. In the northern part of the basin, lower sediments unconformably overlie the Paleogene.

The Neogene sedimentation began in Baden with conglomerate beds that represent immediate underlying productive layers. It consists of epiclastic volcanic conglomerates and sandstones with irregular to lentil-formed bedding.

Coal-bearing sediments are represented by the Nováky and Handlová beds of Sarmatien age, respectively. There is one developed coal bed in Handlová part, while in the Nováky, there is the so called main coal bed, with a thickness of about 10 m (Petrik - Verbich, 1995). The coal bed are autochtone and they often contain tonsteins and carbonaceous shale partings. The coal beds in the Handlová have complicated tectonic structure, while in the Nováky deposit there is overwhelming germanotypic structure (Petrik - Šimeček, 1988). The faults general trend is N-S with minor faults displaying a NE-SW direction, only in northern part of the Nováky deposit is the trend of the faults NW-SE dominate.

Coal-bearing overlying rocks consist of claystone and marls beds of the Koš that in Nováky deposit consist of diatomitic claystone. In higher stratigraphicly rocks there is a deposit, consisting of detritic-volcanic rocks of the Lehota group. In the Handlová deposit overlying the Lehota group are deposits volcanism related to the of Vtáčnik mountains. They are consist of flows of andesites and pyroclastics.

### Coal - petrographic characteristic of coal beds

The coal beds of Nováky contain the following coal lithotypes, in order of importance: detritic, xylitic-detritic, xylitic, detritic-xylitic and mother of coal. The dominate maceral group in the coal is huminitic, represented by humotelinite, humodetrinite and humokolinite. Other maceral groups identified included liptinite (kutinite, suberinite, rezinite) and inertinite (inertodetrinite, fuzinite and sklerotinite).

Vitrinite data the coal Nováky bed is consistent with the brown-coal stage of the coalification with medium vitrinite reflectance: $R_0$ = 0.275%. The coals from the Handlová deposit, influenced by overlying volcanic rocks, have higher coalification with a medium reflectance of vitrinite: $R_0$ = 0.324%.

### The mineralogy of the Nováky coal beds

Is a predominance of clays tonsteins, tuffite, quartz, sulphides of iron and arsenic, and dolomite. Iron sulphides (pyrite, marcasite) most have form of micronodule. Arsenic sulphides (realgar and auripigment) occur at discontinuity areas (layered areas, dilatation cracks, dislocations) and are related to the Vtáčnik volcanic event (Petrik - Šimeček, 1988).

Within the geochemical-ecological survey of the Nováky coal deposit (Vrána et al., 1991) were in coal identified following minerals by means of RTG-analysis, optically mineralogy and spectrochemically analysis:

- silicates - plagioclase and K-feldspar, biotite, chlorite, muscovite, pyroxenes, amphiboles, garnets, clay minerals (mainly kaolinite, illite, minor halloyzite and montmorillonite), hydromicas;
- carbonates - calcite, siderite, manganocalcite;
- phosphates - apatite (?), rock phosphate;
- oxides - quartz, opal, limonite, magnetite;
- sulphides - pyrite, arsenopyrite, realgar, auripigment;
- sulphates - gypsum, anhydrite, melanterite.

From mineralogical research results of the Nováky coals reveal autigenous and allogenous minerals, and detrital minerals, or minerals of the hypergenous zone.

### Geochemistry and chemical-technological characteristics of coal

Coal geochemistry of the Handlová-Nováky coal basin has been object of intensive study since 60's. Over the years, various analytical methods were used, and various element suites were investigated.

Petrik (1964) performed 102 coal analyses and 32 samples by qualitative spectral analyses. From the coal analyses he revealed that sulphur contents in the Nováky coals of ranged from 1.81-11.57% with the modal interval 3-5%.

Mecháček-Petrik (1967) studied coal bed geochemistry from Handlová-Nováky coal basin. Based on 400 semiquantitative spectrochemical analyses of coal sampled from the Handlová, Cígeľ and Nováky mines, element contents were classified in following groups:

- amount above 1%: Al, Ca, Fe, K, Mg, Si, rarely Ba, Na;
- 0.01- 1%: Ba, Mn, Ti, rarely Be, Na, Sr;
- 0.01% - traces: B, Be, Mn, Sr, Ti, rarely Ag, As, Ba, Co, Cr, Cu, Mo,Ni, Pb, V, Zn;
- rarely or only in some areas, most only in trace contents: As, Bi, Cd, Ga, Ge, Li, Sb, Zn, W.

Mecháček (1975) studied qualitative and quantitative trace elements distribution and their relationships in the coals from Tertiary basins of Slovakia. For the Nováky some very high contents of B, Ba, Sr a Ge (Tab. 1), a statistical correlations of the elements resulted in the following values: Ni/Co = 0.8, Ba/Sr = 0.9, B/Ba = 0.6, B/Sr = 0.7, B/Cu = 0.5, B/Ni = 0.5, V/Ni = 0.7, V/Cr = 0.5, V/Co = 0.6, V/Cu = 0.6, Cu/Co = 0.7.

*Table 1: Statistical characteristics of trace element distribution in coal (ppm)*

| Element | Minimum | Average | Maximum | Median |
|---|---|---|---|---|
| B | 20 | 1665 | 3200 | 150 |
| Ba | 100 | 1170 | 3000 | 800 |
| Sr | 70 | 965 | 3000 | 490 |
| Ni | 5 | 25 | 90 | 20 |
| Co | 2 | 10 | 80 | 10 |
| V | 10 | 125 | 740 | 80 |
| Cr | 5 | 35 | 360 | 20 |
| Cu | 5 | 50 | 280 | 35 |
| Pb | - | 56 | 310 | - |
| Ge | - | 15 | 170 | - |
| Mo | - | 22 | 70 | - |

Petrik -Šimeček (1988) studied elements distribution and compared the three parts of the Handlová-Nováky coal (Tab. 2), whereby the Nováky deposit was based on the average highest concentration: Sr, Ge and Pb, respectively. The authors studied coal petrographical composition, carbonization rate, and mineralogy of the coal bed. Main significance is of their study regional resource characteristics, petrographical lithotype and the influence of hydrothermal solutions.

*Table 2: Mean trace elements values (ppm)*

| Element | Handlová | Cígeľ | Nováky |
|---|---|---|---|
| B | 2300 | 1890 | 1600 |
| Ba | 1620 | 1300 | 1300 |
| Sr | 880 | 740 | 1250 |
| Cr | 90 | 73 | 45 |
| V | 440 | 195 | 210 |
| Ni | 100 | 75 | 30 |
| Co | 50 | 20 | 20 |
| Ge | ? | ? | 10 |
| Cu | 205 | 150 | 65 |
| Pb | 30 | 25 | 55 |
| Ag | traces | traces | traces |
| Sn | 15 | 34 | 12 |
| Mo | 40 | 24 | 22 |

Halmo, J. et al. (1991 in Vrána et al., 1991) studied the distribution of As and S in coal from Nováky in 73 exploratory wells, drilled during 1977-1990 survey. The authors concluded the following As distribution heterogeneity:

- As content is highest in a coal uppermost part and it is decreasing towards bottom (24 boreholes). As highest content was in the borehole Z-309 - 3.64%. As contents maximum contents
- occur near the roof rocks contact and ranged from 0.1% to 0.3% and rarely 0.06-0.07%.
- As content is lowest in a seam upper part and increases towards underlying bed: 7 boreholes. This is contrary trend, when compared to above case. This type of trend in vertical As distribution is less frequent in the Nováky deposit. Below the roof rock contact As values range 0.01-0.04%, and above seat rock As ranges from 0.1 to 0.14%.
- As content is nearly uniform throughout the coal bed profile: 17 boreholes. This distribution type should be used for the boreholes, where is not possible to follow the change in As content in vertical direction. As determined contents range in interval 0.03-0.14%.
- As content maximum is below the roof rock contact, and from it decreases both towards the seat rock and roof rock - 25 boreholes.

As content in coal of the Nováky deposit, with some exceptions, decreases from the roof rock to the seat rock. Sulphur content show similar trends in vertical distribution.

Vrána et al. (1991) using geochemical, mineralogical and ecological research tools studied both chemical element and their lateral distribution. Element contents were determined by AAS method. Based on lateral variations elements can be classified in following six groups:

- The element contents decrease in N and NE directions from the deposit with no distanced local maximums and minimums in central and northern parts of the deposit - As, Ba, Cr, Fe, Ge, S, and Sr.
- Increase in NE direction - Mn.
- Increase in W direction - B, Cd, Cu and Pb.
- Medium growth in direction towards the deposit center - Cl.
- Medium decrease towards the center of deposit with no distanced marked local maximums and minimums - Hg, Mo, Ni, Sb, Se, V, and Zn.
- No visible trends of the elements - F, Sn.

Element distribution mean values and caloricity values in the vertical direction of a coal bed and interstratified beds are documented in Table 3. Distribution character of ecologically most sensitive elements in "main coal" bed is summarised in Table 4, and from it is very clear their distribution is high variability at coal bed average thickness of 8.35 m.

Mean content of S in Nováky coal is 3.4%. Lowest S content are in upper part of coal seam (3.03%) and they increase with depth to 3.17% in middle part of the coal bed, and 3.76% in bottom part. Mean S contents in the volcanoclastics, when compared with coal, are nearly 1.77%, and lowest in interstratified beds of "main coal" bed (1.25%). Sulphur content in the volcanoclastics also moderately increase with depth.

From genetic view sulphur in the Nováky coal deposit can be divided into four basic types:

- sulphide-S, mainly pyrite, less realgar and auripigment;
- sulphate-S, mainly gypsum, less anhydrite and melanterite, into this group is included sulphur precipitated from sulphate and water (liquid) phases;
- organic-S;
- elementary-S, a product of secondary pyrite decomposition.

Arsenic: mean As content in the Nováky coal is 900 ppm and in interstratified beds is 941 ppm. Minimum and maximum As contents for coal are 249 a 3137 ppm, with most analysed samples in the range 600-800 ppm (31 samples). As contents are related with sulphide minerals (realgar and auripigment, but there is an assumed on organic matter). With depth, As content in the Nováky coal decrease from 1121 ppm in the upper part of the coal, 880 ppm in the central part, to 770 ppm in bottom part. In roof rock of "main coal" bed mean As content is 522 ppm. Similarly As decreases with depth and also occurs in terrigene-volcanogenic interstratified beds.

Caloricity: the mean value of the Nováky coal is 12.08 MJ. The coal from the "main coal" bed central part has highest caloricity - 12.30 MJ and in direction to roof stone and seat rock id decreases in 0.64 or 0.72 MJ, respectively in the coal of the underlying seam the heating value is 9.95 MJ.

Hydrogeochemical studies of the Nováky deposit mine-water showed that water chemistry has following

*Table 3: Mean values of selected elements and coal heating value in the Coal deposit of Nováky*

| Units | N | Q | S | As | F | Cl | B | Hg | Cd | Pb | Se | V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MJ | % | ppm | | | | | | | | | |
| 1 | 154 | 11.86 | 3.29 | 860 | 659 | 56 | 270 | 0.06 | 0.13 | 4.52 | 0.14 | 50.0 |
| 2 | 138 | 12.08 | 3.24 | 900 | 663 | 57 | 280 | 0.06 | 0.12 | 4.25 | 0.14 | 46.0 |
| 3 | 21 | 11.66 | 3.03 | 1 121 | 664 | 54 | 277 | 0.06 | 0.11 | 7.74 | 0.15 | 39.0 |
| 4 | 94 | 12.30 | 3.17 | 880 | 667 | 54 | 296 | 0.05 | 0.12 | 3.67 | 0.14 | 45.1 |
| 5 | 23 | 11.58 | 3.76 | 770 | 652 | 75 | 217 | 0.07 | 0.14 | 3.60 | 0.13 | 56.9 |
| 6 | 16 | 9.95 | 3.66 | 522 | 614 | 42 | 180 | 0.08 | 0.17 | 6.50 | 0.17 | 79.7 |
| 7 | 27 | 3.00 | 1.77 | 941 | 668 | 62 | 137 | 0.08 | 0.16 | 8.60 | 0.29 | 87.9 |
| 8 | 7 | 2.53 | 1.25 | 1 375 | 741 | 70 | 95 | 0.05 | 0.17 | 10.40 | 0.33 | 33.6 |
| 9 | 10 | 3.60 | 2.25 | 336 | 575 | 38 | 147 | 0.10 | 0.14 | 8.40 | 0.33 | 121.0 |

| Units | Cr | Ge | Cu | Sr | Ba | Zn | Mn | Fe | Sb | Mo | Sn | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ppm | | | | | | | | | | | |
| 1 | 8.00 | 3.0 | 8.10 | 170 | 170 | 32 | 249 | 10 329 | 0.14 | 3.0 | 1.0 | 9.00 |
| 2 | 9.00 | 3.0 | 7.10 | 186 | 178 | 32 | 225 | 8 844 | 0.14 | 2.7 | 1.0 | 10.00 |
| 3 | 11.00 | 7.7 | 7.80 | 78 | 168 | 25 | 253 | 6 721 | 0.16 | 3.1 | 1.0 | 15.00 |
| 4 | 7.70 | 2.2 | 6.50 | 243 | 190 | 29 | 217 | 7 716 | 0.14 | 2.6 | 1.0 | 7.50 |
| 5 | 9.40 | 2.7 | 8.70 | 50 | 146 | 51 | 227 | 12 468 | 0.11 | 2.4 | 1.0 | 13.00 |
| 6 | 5.20 | 3.9 | 16.30 | 35 | 87 | 34 | 464 | 23 246 | 0.09 | 1.2 | 1.0 | 4.00 |
| 7 | 14.80 | 3.2 | 16.40 | 250 | 209 | 48 | 289 | 16 079 | 0.20 | 2.3 | 1.3 | 18.70 |
| 8 | 9.10 | 1.0 | 11.70 | 643 | 478 | 42 | 295 | 12 508 | 0.30 | 1.0 | 2.8 | 7.10 |
| 9 | 20.60 | 5.7 | 18.60 | 148 | 129 | 53 | 252 | 20 438 | 0.12 | 2.0 | 1.0 | 26.90 |

Notes: 1 - coal total, 2 - coal. main coal seam, 3 - coal. main coal seam upper part, 4 - coal. main coal seam central part, 5 - coal. main coal seam bottom part, 6 - coal. seat rock of main coal seam, 7 - terrigenic-volcanogenic cliffs total, 8 - terrigenic-volcanogenic cliffs of main coal seam, 9 - terrigenic-volcanogenic cliffs in seat rock

*Table 4: Elements of environment concern in main the coal seam (N = 138)*

| Parameter | S | As | F | Cl | B | Mn | Fe | Zn | V | Ba |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | ppm | | | | | | | | |
| Minimum | 1.59 | 249 | 364 | 13 | 65 | 25 | 569 | 7 | 1 | 1 |
| Mean | 3.24 | 900 | 663 | 57 | 280 | 225 | 8844 | 32 | 46 | 178 |
| Maximum | 8.25 | 3137 | 1420 | 386 | 684 | 813 | 51528 | 365 | 213 | 1627 |
| Standard Deviation | 0.79 | 504.8 | 197 | 53 | 121 | 122 | 6714 | 39 | 42 | 210 |

character: Ca-Mg-$HCO_3$, Na-$HCO_3$, Na-Ca-$HCO_3$. The mine-waters are lower in sulphate, and therefore in the silicate-hydrosilicategenous water group.

Elements of ecological concern (Ni, Se, Sr, Co, Cd, Pb, Hg) are mobilized only slightly by ground water and their concentrations in ground water are below limits defined by the drinkable water standard. Studies revealed that As contents, predominantly in pore-water reach values that are higher than the standard. There is only mobilization of Zn and Cu in ground water. Concentrations of Sr, Fe, Mn and Al have heterogeneous and from ecological point of view, introduce no serious problem.

Because of the possible future use of Handlová-Nováky basin coals utilizing new technologies and developing new products mean values of selected chemical and technological parameters are given in Table 5 (Boroška, 1995).

**Coal exploitation and use**

The Nováky coal deposit is located in the western part of the Upper Nitra basin and has a total area 37 km$^2$. The Nováky coal deposit was discovered during 1937-1938. In 1937, V. Čechovič mapped the Čausa's formation (eggenburgien) towards to the west Nováky deposit. Based on this information he came to the conclusion that of Nováky area should contain an independent coal deposit and it should be a thinness extension of the deposit of Handlová. Drilling started in 1939 under Mr. Čechovič leadership and confirmed the existence of the coal deposit (Halmo - Verbich, 1995). The coal rights, in the mineral territory of Nováky, were obtained Handlovské uhoľné bane, mining company in March 27, 1940, when first inclined shaft started to be driven.

Brown coal production in the Nováky deposit in period 1940-1994 is shown in Figure 1. Exploitation steadily increase, reaching a maximum in 1964 (1943.9 kt). Since 1964 exploitation decreased until 1980 (1256.2 kt), and then it increased gradually until 1985. Since 1985 exploitation has permanently decreased. During the exploitation history of the Nováky deposit three deep mines have been in operation: the Mine Youth (1940-42, 1948-presence), the Mine of Peace (1942-1977), the Mine Le-

*Tab. 5: Coal quality parameters and major oxides for the Handlová-Nováky coal basin*

| Parameter | Symbol | Unit | Cigeľ mine | Handlová mine | Nováky mine |
|---|---|---|---|---|---|
| Caloricity | $Q_i$ | MJ/kg | 11.56 | 12.90 | 10.70 |
| Water | $W^a_t$ | % | 20.70 | 24.32 | 33.90 |
| Ash | $A^a$ | % | 15.20 | 33.90 | 7.00 |
| Volatile substances | $V^{daf}$ | % | 55.60 | 55.04 | 57.62 |
| Arsenic | $As^r$ | ppm | 62 | 67 | 590 |
| Sulphur total | $S^r_t$ | % | 1.35 | 1.36 | 1.99 |
| of it: organic | $S_o$ | % | 0.79 | 0.82 | 0.83 |
| sulphatic | $S_{SO4}$ | % | 0.11 | 0.10 | 0.10 |
| pyritic | $S_p$ | % | 0.47 | 0.44 | 1.06 |
| Sulphur in ash | $S_A$ | % | 0.31 | 0.13 | 0.69 |
| Sulphur volatile | $S_C$ | % | 1.04 | 1.23 | 1.30 |
| Carbon | $C^{daf}$ | % | 63.5 | 62.9 | 59.5 |
| Hydrogen | $H^{daf}$ | % | 8.86 | 8.09 | 9.66 |
| Nitrogen | $N^{daf}$ | % | 5.36 | 6.71 | 5.74 |
| Oxygen | $O^{daf}$ | % | 26.32 | 24.38 | 27.31 |
| Ash | | | | | |
| $SiO_2$ | | % | 45.6 | 50.4 | 44.2 |
| $Al_2O_3$ | | % | 18.6 | 17.4 | 19.8 |
| $Fe_2O_3$ | | % | 13.8 | 12.0 | 12.3 |
| CaO | | % | 8.6 | 5.3 | 8.7 |
| MgO | | % | 4.3 | 3.2 | 4.8 |
| $Na_2O$ | | % | 0.67 | 0.95 | 1.04 |
| $K_2O$ | | % | 1.71 | 1.69 | 1.92 |
| Start of caking | $t_s$ | °C | 900 | 960 | 925 |
| Point of softing | $t_A$ | °C | 1220 | 1200 | 1200 |
| Point of melting | $t_B$ | °C | 1295 | 1360 | 285 |
| Point of flowing | $t_C$ | °C | 1310 | 1310 | 1280 |

hota (1952-1993) and one surface mine Lehota (1980-1988).

The Hornonitrianske bane š.p. (Mines of Upper Nitra) is producing approximately 2.8 million tons coal and lignite. The Baňa Cígeľ mine production is 29%, Baňa Handlová 31% and Baňa Nováky 40% of the total respectively. The Cígeľ and Handlová mines produce brown coal, and Nováky mine lignite. All coal production has been used for electric-power generations both small-scale and large-scale (mainly ENO Power Station, Zemianské Kostoľany), and chemical processing (Chemical works, Nováky). Nováky coal was exported to Schweiz during period 1943-1944 and was used mainly for chemical processing (Boroška, 1995).

## Physiography of the Upper Nitra region

The Prievidza region is a partly closed basin with the south side open and by Nitra catchment basin connected with Nitra Basin. Considerable area is occupied by the Strážovské vrchy mountains, as well as the mountains ranges of Vtáčnik, less Malá Fatra, Žiar and Kremnické vrchy and Tribeč. Climatic conditions are represented by three climatic zones (warm, medium warm, and cool ones). Average annual temperature is 8.5°C with a annual precipitation of 685 mm. The region covers is 960 km$^2$ which is less than 2% of total Slovakia. Population of the region is 140 000 with a population density 147 inhabitants per km$^2$.

The region can be characterized as 37% agricultural and 53% forest. Natural soil conditions are normally, level and markedly differentiated. The agricultural land is suitable for cereals (20%), and for fodder crops (19%).

The existence of coal and the natural resources have influenced the region and changed it from agricultural to industrial. With this change power stations, chemical plants, engineering industry, production of constructional materials, shoe industry, textile industry, and other processing plants have developed in the region. Rapid growth of industry has also influenced the region (employment, dwelling construction, services, etc.), however their environmental influence has been negative.

## Soils and their geochemical characteristics

Soil character and development in Upper Nitra region are controlled by geological structure, hydrological, and geomorphological conditions. Thirteen soil types have been identified in the region (Ranker, Rendzina, Pararendzina, Phaeozem, Orthic Luvisol, Albic Luvisol, Eutric Cambisol, Mollic Andosol, Podzol, Pseudogley, Gley, Fluvisol, Kultisol) with several forms and varieties. Most common are loamy soils, sand-loamy soils, and silty soils. Most productive agricultural soils (Fluvisols, Luvisols, Cambisols, and Pseudogleys) are protected in the region. Landscape morphology has marked influence on

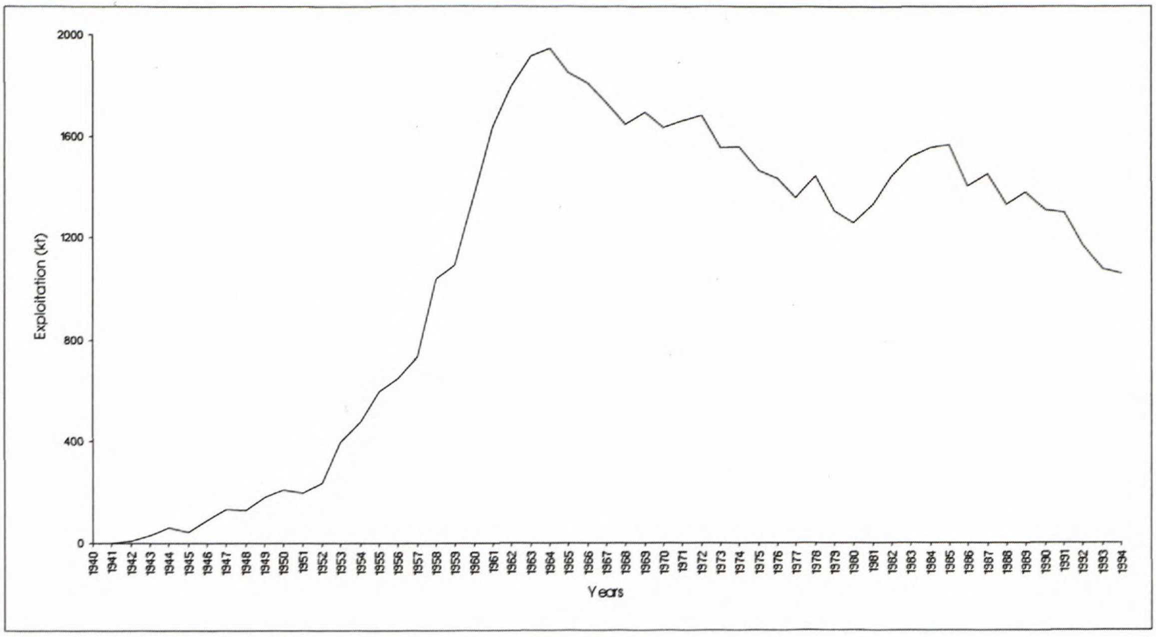



*Figure 1: Coal production history for the Nováky mine*

water erosion. Erosion risk in Prievidza county has been evaluated and listed below (Čurlík et al., 1993):

- week and medium erodible soils - 42.3%
- severely erodible soils - 16.5%
- very severely erodible soils - 4.7%.

Landslide have been delineated in the areas of Handlová, Chrenovec, Veľká Čausa and Malá Čausa, and is related to natural conditions (geological structure, hydrology and morphology of territory) and for land use.

The Prievidza region industrialisation has also effected on farming land use. Their acreages are permanently decreased due to mining activities, building up coal processing measures, construction of setting pits, and pit spoilpiles and to soil contamination with risk elements of organic and inorganic character.

Čurlík - Šefčík (1994) studied 60 Slovakian soil profiles and sampled the A and C horizons for analyses for total content 36 elements. Statistical analysis of risk elements contents (Tab. 6) conformed that soils of the region are enriched in A horizon, or contamined with elements As, Cd, Cr, Cu, Mo, Pb, Sb, and Zn, when compared to C horizon. On average risk elements contents do not exceed the limits given by legislation (MP SR, 531/1994-540), but some partial values of the set exceed the limits. This contamination results from processing technology and the coal utilization from the Handlová-Nováky basin. It is interesting that fluorine and mercury contents in C horizon are relatively higher than in A horizon and is the result of the mineralogical and petrographical composition of soil substrata.

## Main direction of economical and social development of the region with aspect to environment

In agricultural and food industry it will be necessary, with aspect to ecological load of the region (38% farming land), to develop new guidelines for specific types of farming focused on special crops for industrial processing. Concrete possibilities are in winter rape and its processing to bionafta. Its should be oriented mainly to the farms focused on alternative farming types, to protected areas of water management, and for local transport vehicles.

Conservation of soil, forest and rock environment needs to reduce large-scale production of food crops in areas with chemical contamination (Nováky-Oslany). Similarly is desirable to look for a solution of the exploited coal mine lands used in the region and to implement revitalisation of the region disturbed by mining activities and areas eroded after deforestation.

Atmosphere purity will be conditioned by environmental constructions implemented by the ENO Zemianské Kostoľany. With these new additions marked reductions of $SO_2$ and nitrogen oxides emissions, and ashes; significant reduction of As, Cl, F and other risk elements. Similarly modernisation and new technologies application manufacture processes of the Chemical works, Nováky are planned and will reduce emissions of heavy metals, volatile organic substances, solid substances, and Cl and freons.

With the substantial increase of water pollutants there is a need to reduce pollution of waters by implementation of cleanwater technologies.

An important task will be the design of a waste economy, both from qualitative and quantitative aspects and increased waste recyclation. Main problem are ashes and other wastes from electric power plants and district heating plants, wastes from the building industry, and raw material exploitation, wood industry, rubber industry, and chemical industry.

## Conclusions

From qualitative point of view the Nováky coal most important are characteristic the following:

*Table 6: Distribution of elements in Prievidza region soils*

| Descriptive Statistics of A-horizon | Trace elements (ppm) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | As | Ba | Cd | Co | Cr | Cu | F | Hg | Mo | Ni | Pb | Sb | Se | Zn |
| Mean | 20.8 | 383.5 | 0.5 | 10.4 | 68.3 | 17.8 | 380.0 | 0.2 | 0.7 | 23.8 | 34.1 | 1.1 | 0.1 | 78.0 |
| Median | 16.2 | 397.0 | 0.5 | 10.0 | 70.0 | 15.5 | 300.0 | 0.1 | 0.5 | 19.0 | 29.5 | 0.8 | 0.1 | 72.0 |
| Mode | 11.2 | 399.0 | 0.2 | 10.0 | 90.0 | 14.0 | 150.0 | 0.1 | 0.5 | 24.0 | 26.0 | 0.9 | 0.1 | 57.0 |
| Standard Deviation | 15.3 | 104.0 | 0.3 | 3.7 | 25.0 | 8.4 | 382.7 | 0.1 | 0.7 | 18.0 | 18.4 | 0.8 | 0.1 | 38.1 |
| Minimum | 3.9 | 103.0 | 0.1 | 3.0 | 18.0 | 6.0 | 150.0 | 0.0 | 0.1 | 0.5 | 13.0 | 0.3 | 0.1 | 26.0 |
| Maximum | 90.0 | 587.0 | 1.7 | 21.0 | 130.0 | 44.0 | 1850.0 | 0.8 | 4.5 | 100.0 | 90.0 | 4.2 | 0.4 | 199.0 |
| Count | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Descriptive Statistics of C-horizon | Trace elements (ppm) | | | | | | | | | | | | | |
| | As | Ba | Cd | Co | Cr | Cu | F | Hg | Mo | Ni | Pb | Sb | Se | Zn |
| Mean | 28.3 | 396.5 | 0.3 | 11.3 | 71.2 | 17.6 | 454.0 | 0.1 | 0.6 | 28.0 | 18.2 | 0.7 | 0.1 | 65.4 |
| Median | 7.1 | 417.5 | 0.3 | 10.5 | 67.5 | 15.0 | 300.0 | 0.1 | 0.4 | 21.5 | 14.0 | 0.5 | 0.1 | 52.0 |
| Mode | 1.7 | 289.0 | 0.2 | 7.0 | 61.0 | 11.0 | 150.0 | 0.1 | 0.1 | 25.0 | 11.0 | 0.3 | 0.1 | 48.0 |
| Standard Deviation | 128.1 | 143.6 | 0.3 | 4.6 | 26.9 | 11.0 | 442.7 | 0.5 | 0.7 | 24.8 | 11.1 | 0.8 | 0.1 | 39.2 |
| Minimum | 0.9 | 135.0 | 0.1 | 3.0 | 11.0 | 2.0 | 150.0 | 0.0 | 0.1 | 0.5 | 8.0 | 0.1 | 0.1 | 24.0 |
| Maximum | 913.0 | 829.0 | 1.2 | 22.0 | 143.0 | 52.0 | 2000.0 | 3.4 | 3.6 | 124.0 | 54.0 | 4.9 | 0.4 | 248.0 |
| Count | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

- highest caloricity in the "main coal" bed was found in its central part;
- sulphur contents were shown to increase with depth;
- sulphur contents in volcano-sedimentary overburden are nearly half, when compared with coal;
- As contents, contrary to sulphur case decrease with depth;
- contents of other harmful elements, F and Cl, in coal and in overburden are approximately the same and do not show significant changes with depth;
- Fe contents in volcanic - sedimentary overburden are approximately twice as much in the coal when compared for the overburden and both increase with depth ;
- lateral element distribution of harmful As, S, Fe decrease to the north of deposit;
- F levels in the deposit are more or less homogenous and Cl contents show moderate increase towards the centre;
- increased S content in the seat rock of coal seam may partly result from the gypsum concentration, its occurrence increased in seat rock.

According to the present ecological situation in the Upper Nitra region national environmental politics in the future should be focused on:

- atmosphere protection against pollutants and global environmental security;
- to secure drinkable water abundance and reduction of remaining water pollution under acceptable rate;
- protection of the soil against degradation and the prevention food contamination as well as other products;
- waste origination minimisation, recyclation and hygiene;
- biological diversity conservation, natural resources rational use and conservation, spatial structure optimisation, and optimum land use.

## References


Boroška, F., 1995: Poznatky o možnostiach netraičného využitia uhlia. Spravodaj 2/3, *Banský výskum*, Prievidza, 170-173 s.

Čurlík, J. et al., 1993: Geochemický atlas pôd Slovenska a súbor máp geofaktorov životného prostredia. Manuscript, VÚPÚ, Bratislava, 82 s.

Čurlík, J. - Šefčík, P., 1994: Geochemický atlas a geochemické mapovanie Slovenska. *Poľnohospodárstvo*, Vol. 40, No. 6, Nitra, 435-446 s.

Halmo, J. - Verbich, F., 1995: Geologická a hydrogeologická stavba nováckeho uhoľného ložiska a bojicej vysokej kryhy. *Spravodaj* 2/3, Banský výskum, Prievidza, 26-42 s.

Mecháček, E. - Petrík, F., 1967: Distribúcia stopových prvkov v uhoľných slojoch handlovsko-nováckeho ložiska. *Geologický pruzkum*, 2, Praha, 266-268 s.

Mecháček, E., 1975: Mikroprvky v uhlí z terciérnych uhoľných panví na Slovensku. Habil. práca, Manuscript - Katedra geochémie PF UK, Bratislava, 194 s.

MP SR: Rozhodnutie MP SR o najvyšších prípustných hodnotách škodlivých látok v pôde a o určení organizácií oprávnených zisťovať skutočné hodnoty týchto látok (číslo 531/1994-540).

Petrík, F., 1964: Komplexný rozbor nováckeho sloja. Záverečná správa, Manuscript, VVÚGG, PF UK, Bratislava, 137 s.

Petrík, F. - Šimeček, M., 1988: The Handlová coal deposit seams: tectonic development and quantitative properties. In: Coal-bearing formations of Czechoslovakia, Thematic volume concerning IGCP project 166, *Konfer.-Symp.-Sem.*, GÚDŠ, Bratislava, pp. 371-382

Petrík, F. - Verbich, F., 1995: Uhoľno-petrografické vyhodnotenie vzoriek uhlia z Handlovsko-nováckej uhoľnej pánvy. *Spravodaj* 4/5, Banský výskum, Prievidza, 208-211 s.

Vrána, K. et al., 1991: Geochemicko-ekologický výskum nováckeho uhoľného ložiska. Záver. správa, Manuscript, GÚDŠ, Bratislava, 118 s.

*Slovak Geol. Mag. 4, 11998, 61–74*

# Asymmetric lithospheric stretching in Danube Basin

DIONÝZ VASS[1] and MIROSLAV PERESZLÉNYI[2]

[1] Fakulty of Forestry, Technical University, Masarykova 24, 960 53 Zvolen, Slovakia
[2]Slovak Gas Industry, VVNP - Research Oil Company, Votrubova 11/a, 825 05 Bratislava, Slovakia

***Abstract:*** Danube Basin is a thermal extensional basin which began to open at the end of the Early Miocene. The main part of the initial synrift phase occurred during the Middle Miocene and the thermal postrift phase closed the filling of the basin during the Late Miocene and Pliocene. Asymmetric stretching controlled tectonic development of the basin. In the outer zone, on the northern margin of the basin (Blatne, Rišnov, Komjatice and Želiezovce depressions) prevailed synrift subsidence. Thermal subsidence occurred in this zone only partly or it was missing. In the inner zone (in the partial Gabčíkovo Basin) both phases of subsidence occurred but the synrift subsidence was relatively small. Locally some areas emerged (Kolárovo elevation). On the contrary thermal postrift subsidence was very intensive and determined deposition of several thousand meters thick deposits only slightly deformed by faults. The basin development is consistent with Coward model of heterogeneous lithosphere thinning (1986).

***Key words:*** Danube Basin, non-uniform lithosphere stretching, asymmetrical continental lithosphere stretching, thermal extension, initial tectonic or synrift subsidence, thermal or postrift subsidence.

## Introduction

Model of Pannonian or (Carpathian) Basin as one basin unit, presented mostly under the influence of geomorphologists and accepted by Stegena et al. (1975) in the first genetic interpretations of gathered geophysical data, is not valid today. The first objections were risen by Vass (1976, 1979). Later an american-hungarian team of geologists and geophysicists came to the similar conclusion when they characterized Pannonian depression area as a basin system (Royden et al. 1983, 1988, Figs. 6 and 7).

The individual basins in the basin system differ by origin and development even if there is some relation among some of them. More of them are thermal extensional basins originated by lithosphere stretching as a result of rising of astenosphere and subsequent warming and stretching of the upper mantle and crust. But also among thermal basins important genetic differences exist:

- The part of them implies by their position above thinned crust and lithosphere the origin by a pure shear lithopheric stretching (McKenzie 1978, Salveson 1976, 1978) or, perhaps most likely, they originated by non-uniform lithosphere stretching (basins Makó, Békes - Royden and Keen 1980, Beaumont 1982, Hellinger & Sclater 1983).
- Other thermal basins of the Pannonian Basin system were opened as a result of heterogeneous lithosphere stretching. The northern Danube Basin is assigned among such basins.

The Danube basin differs from the other Pannonian thermal basins by:

- fluctuation of the crust and lithosphere thickness in the basin area
- contrasting thickness of syn- and postrift deposits in the central and outer (marginal) part
- contrasting subsidence velocity
- differences in the frequency of the occurrence of synsedimentary faults and in the magnitude of their throws.

The Northern Danube Basin lies on the territory of Slovakia and it is consistent with the Danube Lowland according to the regional geographic divisions of the Slovak Republic. The southern part of the basin lies on the Hungarian territory and it is consistent with the Kiss Alföld (Little Hungarian Plain).

The objective of the work is an analysis of the structure of the Northern Danube Basin with emphasis to untangle the mechanism and the history of its opening and subsidence.

The northern part of the Danube Basin, as said above, is consistent with the Danube Lowland. It extends north of the Danube river, stretching by "bays" between mountains of Malé Karpaty Mts., Považský Inovec, Tríbeč. At the NE it is limited by neovolcanics of Štiavnica stratovolcan and Pohronský Inovec Mts (Fig. 1). The structure and development of the above defined part of the Danube Basin are different in comparison with other

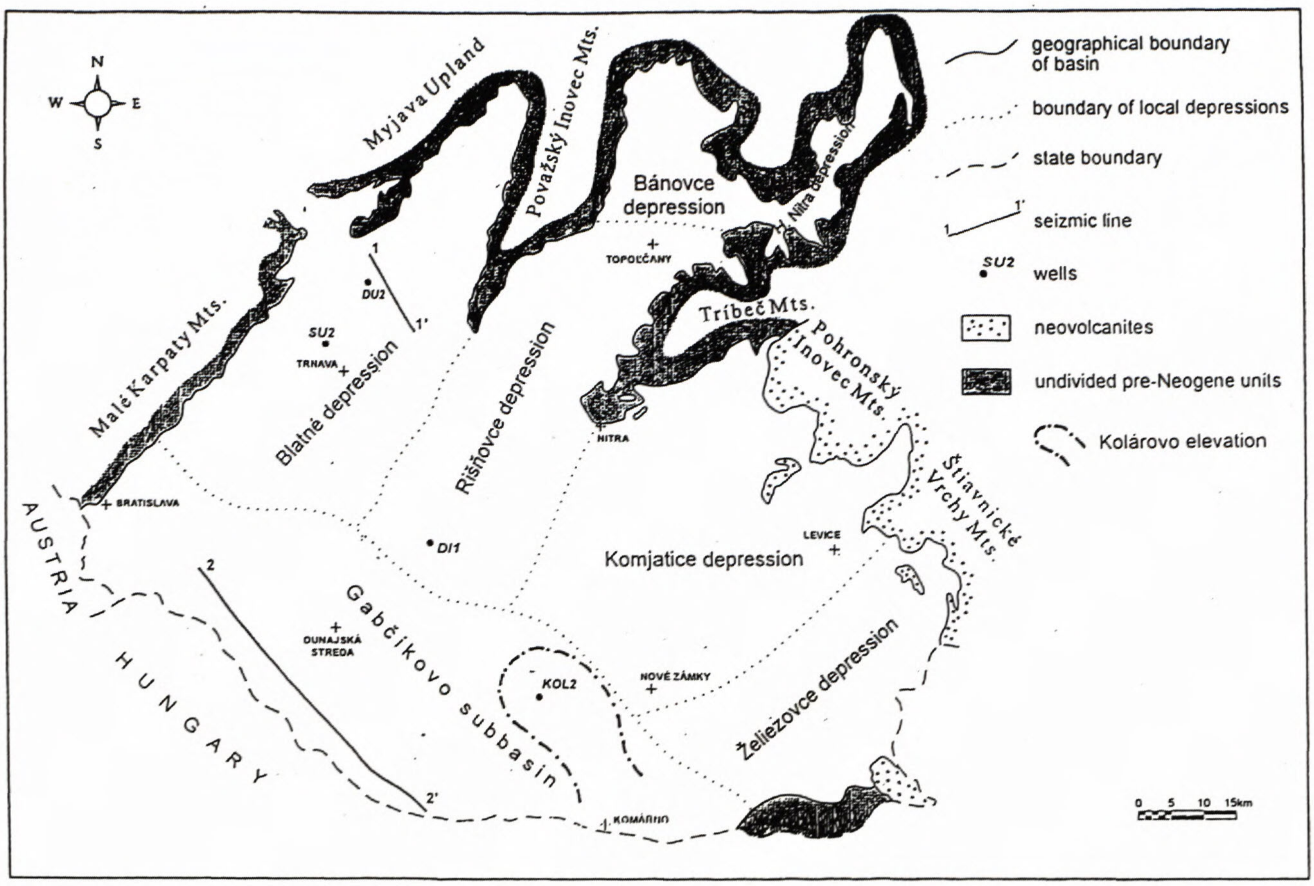



*Fig. 1 Northern part of Danube Basin - Situation of seizmic lines, wells used in the model and regional subdivision*

extensional basins of the Pannonian area. The basic difference is differentiated structural development of partial depressions in "bays" of the northern margin of the basin on one side and partial Gabčíkovo depression immediately north of Danube river on the other side.

## Tectonic history of the area

Numerous important tectonic events preceded the origin of the Danube Basin. During the Paleogene and Early Neogene an extensive lateral movement of elastic lithosphere segments comprising present West Carpathians, Bakonicum and Bükkicum occurred along shear zones or transcurrent faults. This movement occurred contemporaneously with the thrusting of the Outer Flysch Carpathians. Extrusive tectonics as a driving mechanism for the final location of the East Alpine and West Carpathians tectonic units was proposed by Ratschbacher et al. (1991). Extrusive tectonics is defined as a synchronous interaction between tectonic escape (Burke & Sengor 1986) and extension colaps (Deway 1988). It is necessary to emphasize that the structure of the West Carpathians was mainly formed in the Late Cretaceous (Mediterranean phase of thrusting sensu Andrusov 1967). The Eocene or post-Eocene thrusting already was more or less synergic with extensive lateral translation. The process of lateral translation had a character of tectonic escape of lithospheric fragments from the area south of the Northern Alps as a result of continent - continent collision between Apulian promotory and Bohemian Massif. The amplitude of the lateral movement of the lithospheric blocks is on the basis of Bakony unit (Kazmer & Kovacs 1985) assumed to be 500 km. The direction of tectonic escape was toward the south-east although the today's position of the escaped blocks is north-east in relation to the original home area. The reasons for today's position will be explained below.

Contemporary thrusting in the Outer Carpathians helped at least partly to solve the problem of space necessary for escaping lithospheric blocks. The thrusting mainly occurred in the innermost and southermost e.g. Magura Flysch unit, but also in the Dukla and Silezian units (e.g. Stránik in Vass et al. 1987).

The escape of large lithospheric mass triggered a change of the equilibrium state in the asthenosphere. The removal of lithospheric or crustal masses on the surface generates a horizontal stress gradient in the mantle if it is sufficiently rapid. The horizontal stress gradient in the mantle creates, in turn, an elastic mantle mass flow. The mantle mass escapes from areas of increased crust or lithospheric weight into areas of lower crust or lithosperic pressure (Allen & Allen 1992). This is the forming mechanism for convective flows which generate astheno-

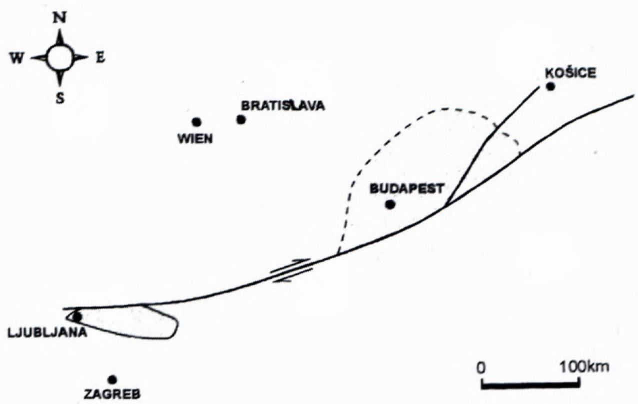



*Fig. 2 Lateral displacement of the Slovenian (Lubljana) and Hungarian Paleogene Basins after the Egerian (according to Csontos et al., 1992)*

sphere rising and thinning of lithosphere. A similar model - the model of extensional colaps introduced by Deway (1988), Molnar & Lyon-Cean (1988) has been applied for the extension in intra-Carpathian space, where extension is explained as a result of thickened and therefore gravititionally not stable crust (Horváth & Berkhemer 1982, Tari et al. 1992).

Warming by convection and conduction heat transfer through lithosphere caused its thinning. If heat flow from the astenosphere was big enough, relatively fast thinning of continental lithosphere and its isostatic uplift occurred (active rifting, Sengor & Burke 1978, Baker & Morgan 1981, Turcotte 1983, Morgan & Baker 1983, Keen 1985, fide Allen & Allen 1992). The condition of sufficiently high heat flow transferred by astenosphere convection as well as the condition of the rapid lithosphere thinning was fulfilled. The escape of lithospheric masses was realized during ca. 12 - 15 Ma (Oligocene - Earliest Miocene) when the rash translation documented by the spatial redistribution of Slovenian Paleogene in relation to the Hungarian Paleogene basins occurred. This translation, which occurred after the Eggerian e. g. after 22 Ma B.P. (Csontos et al. 1992), was carried out by the dextral strike slip along the Balaton line in the range about 300 km (Fig. 2). The first surface manifestation of the uplift phase of the active rifting are dated to the end of Eggenburgian e.g. to the time span ca. 20 - 19 Ma B.P. The proves of prerift uplift are Bukovina (southern Slovakia), Zagyvapalfalva (northern Hungary), Sásvár (Mecsek and surroundings, Zala and Dráva Basins), Madaras (Alföld) and Brenberg (surroundings of Šopron) Formations (Fig. 3). They consist of continental deposits (fluvial etc.) discontinuously spread in the entire modern Pannonian Basin, including depressions of southern Slovakia. They lie on the either marine deposits of

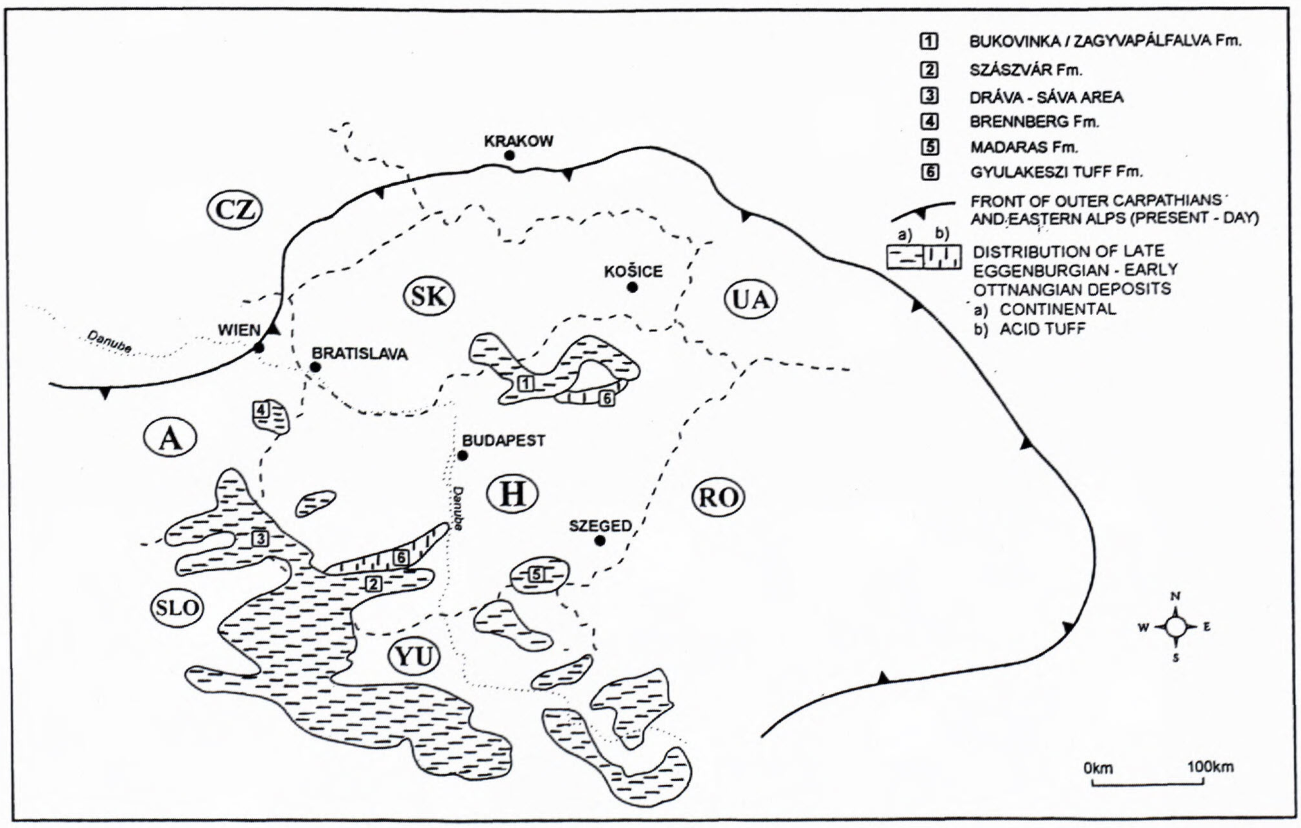



*Fig. 3 Continental formations Late Eggemburgian – Early Ottnangian in age, distributed in the „Pannonian area". Areas in between are assumed to have been exposed to erosion. The picture clearly documents the regional uplift in the whole area of present-day Pannonian Basin (according to Hámor et al., 1988, modified and completed by authors).*

Early Eggenburgian (on Fiľakovo and Pétervásar Formations) or older rocks (e.g. Čechovič 1952, Seneš 1951, Vass et al. 1979, 1989, 1992, Csasar & Haas 1983).

The continental formations document a change from marine depositional environment to continental environment, thus an uplift and sea regression in the Pannonian space inspite of the global sea level rise trend in the time span 21 - 17.5 Ma (Techas TB 2.1, Haq et al. 1987).

The continental deposits are accompanied by rhyodacite/rhyolite tuffs of areal extent (Lexa et al. 1993) with radiometric ages 19.7 and 20.1 Ma in the southern Slovakia (Kantor et al. fide Vass et al. 1992, Repčok 1987) and 17 - 19 Ma in the north-eastern Hungary (Hámor et al. 1980).

The uplift lasted from the end of Eggenburgian to the Early Ottnangian representing time span 1-2 Ma. The prerift uplift is also recorded in the East-Slovakian Basin which is evidenced by the lack of the Ottnangian deposits (Fig. 4).

The own rifting followed the uplift phase. The first subsidence, controled by faults, already commenced during Ottnangian in the Pannonian area. The result of the subsidence is a sea incursion into surroundings of Várpaloty (Bántapusta Formation, Kokai in Papp et al. 1973). Indication of the beginning of the marine transgression is also a paralic coal sedimentation in Borsode area (north-eastern Hungary, Bohn-Havas 1985) and marine ingressions into fluvial-palustrine environment (into coal-bearing Pôtor Member) and later into lacustrine environment (Plachtince Member) of Ottnangian age in the southern Slovakia (Vass et al. 1987, Škvarka et al. 1991). In this period, extension controlled palaeostress field (Vass et al. 1993, Márton & Fodor 1995). On the contrary in the Carpathian front next thrust phase of Flysch Carpathians and their overthrusting on the Carpathian foredeep occurred (e.g. Jiříček 1979, Vass et al. 1983, Oszypko and Slaczka 1985).

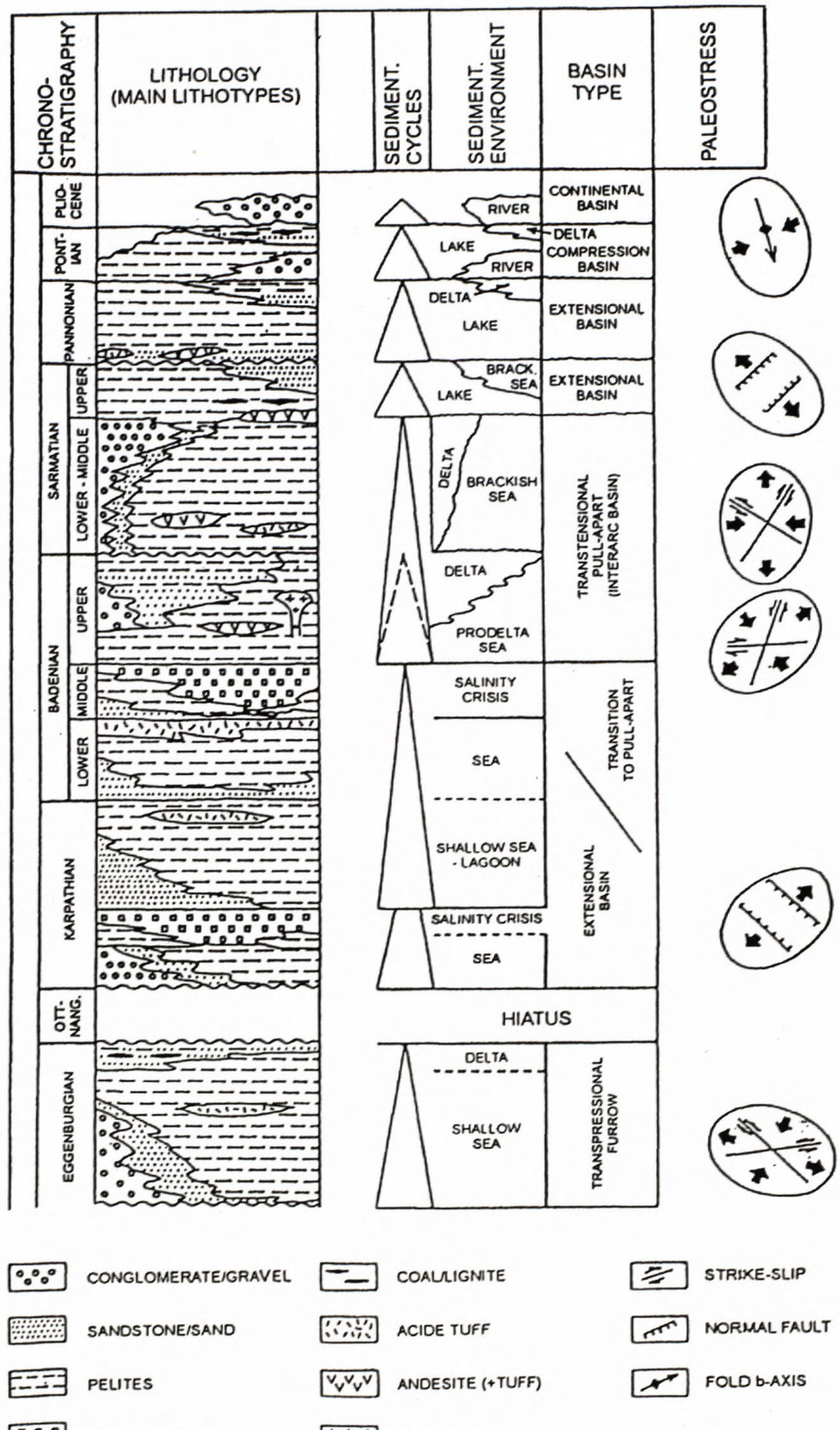



*Fig. 4 Scheme of lithology and tectonic development of East Slovakian Basin (after P. Kováč et al. 1994). The Ottnangian deposits are missing in the basin. See also the extension during the Karpathian.*

On this tectonic background an extensive 50° anticlockwise rotation of the North Pannonian - West Carpathian block or partial blocks occurred. An another rotation in ca. 30° contributed to the first rotation in the Karpatian or during the Early Badenian. The total movement of blocks affected by rotation might be 500 - 1000 km toward the north (Márton et al. 1995, 1996). This mechanism was responsible for today's position of the units which originally tectonically escaped toward the south-east. The units are now located north-east of the original home area in the Alps and Dinarides. It is necessary to say that the rotational transport of the Inner Carpathian units from the south to the north is supported by shallow inclination of remanent palaeomagnetism. Thrusting in the Carpathian front, which means space shortening in the front of the Outer Carpathians and space widening in the inner part in ca. 500 km (Oszczypko & Slaczka, 1985) compensated by anticlockwise (e.g. toward the north) rotational movement of the Inner Carpathian units contributed by a decisive role to the formation of the Carpathian loop (Vass et al. 1988).

The rifting and crustal extension continued in the Karpatian. The relevant style of the crust extension was described by Tari et al. (1992). In the southern part of the Danube Basin (e. g. in the Small Hungarian Plain) an ex tension controlled by normal listric fault which originally represented a detachment plane of pre-Tertiary units was described on the basis of seismic profile. The sinking movement on the fault opened an asymmetric trough restricted by faults in the north-western part and without fault restriction in the south-eastern part (Fig. 5). The oldest deposits of the trough fill are Ligeterdö conglomerates of Karpatian age (17.5 - 16.5 Ma, Steininger et al. 1988). A similar contemporary (e.g. Karpatian) style of opening is preserved in the East-Slovakian Basin. In the pre-Tertiary basement, tectonically formed in the Paleogene (after

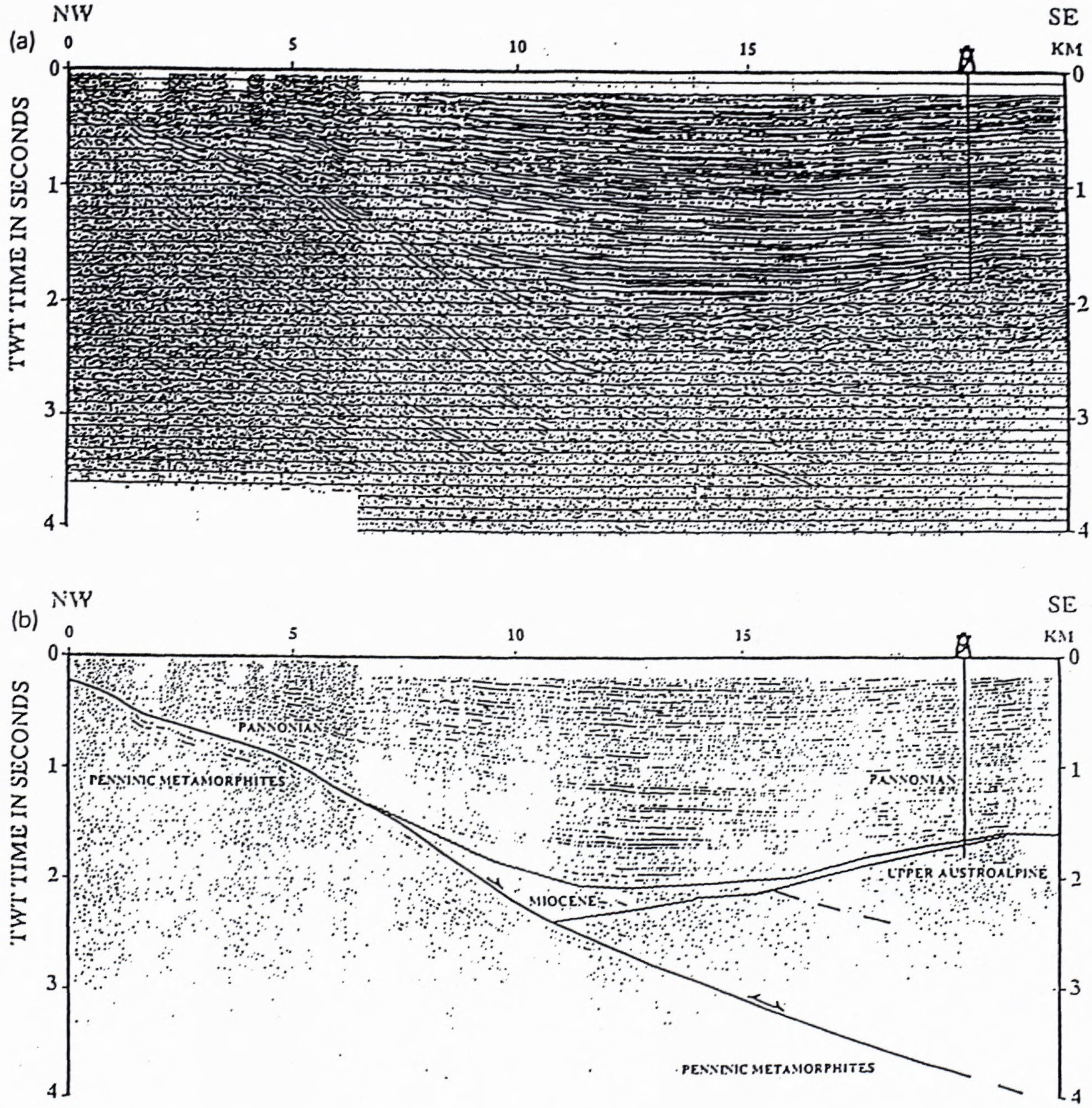



*Fig. 5 Migrated sesmic section (a) and its interpretation (b). The basement consists of epimetamorphic greenschists on the northwestern side of the section, representing the subsurface continuation of Jurassic – Early Cretaceous rocks outcropping in the Penninic window of Rechnitz. The well on the souteastern side of the profile bottomed in anchimetamophic Paleozoic rocks (Graz Paleozoic). The low-angle tectonic contact between these tectonic unit corresponds to a Cretaceous major overthrust plane. During the Middle Miocene the same fault plane reactivated as an extensional detachment fault, along which the metamorphic core complex of Rechnitz was uplifted and the asymmetric graben of middle Miocene through Pliocene in age subsided (after Tari et al., 1992)*

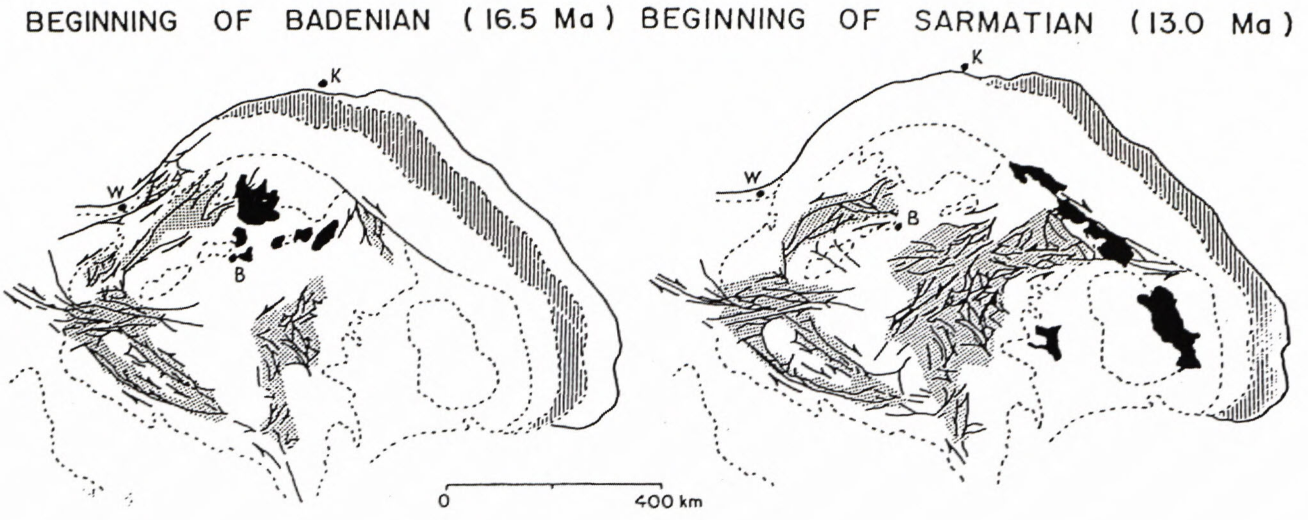



*Fig. 6 Palinspastic reconstruction of the Carpathian – Pannonian region at beginning of Badenian time and beginning of Sarmatian time showing the areas of synrift extension and sedimentation. Solid line shows present external limit of Carpathian flysh and is fixed with respect to Europe. Shaded areas show region af active extension during each time stage (Badenian and Sarmatian); vertical lines indicate areas of shortening; small arrows indicate direction of motion inferred along strike-slip fault zones. Black indicates areas of andesitic volcanism. There are show only the areas of extension, compression and transcurrent faulting which have been identified and are know to belong to the time periods indicated (after Royden et al., 1982).*
*W – Wien, K – Krakow, B – Budapest*

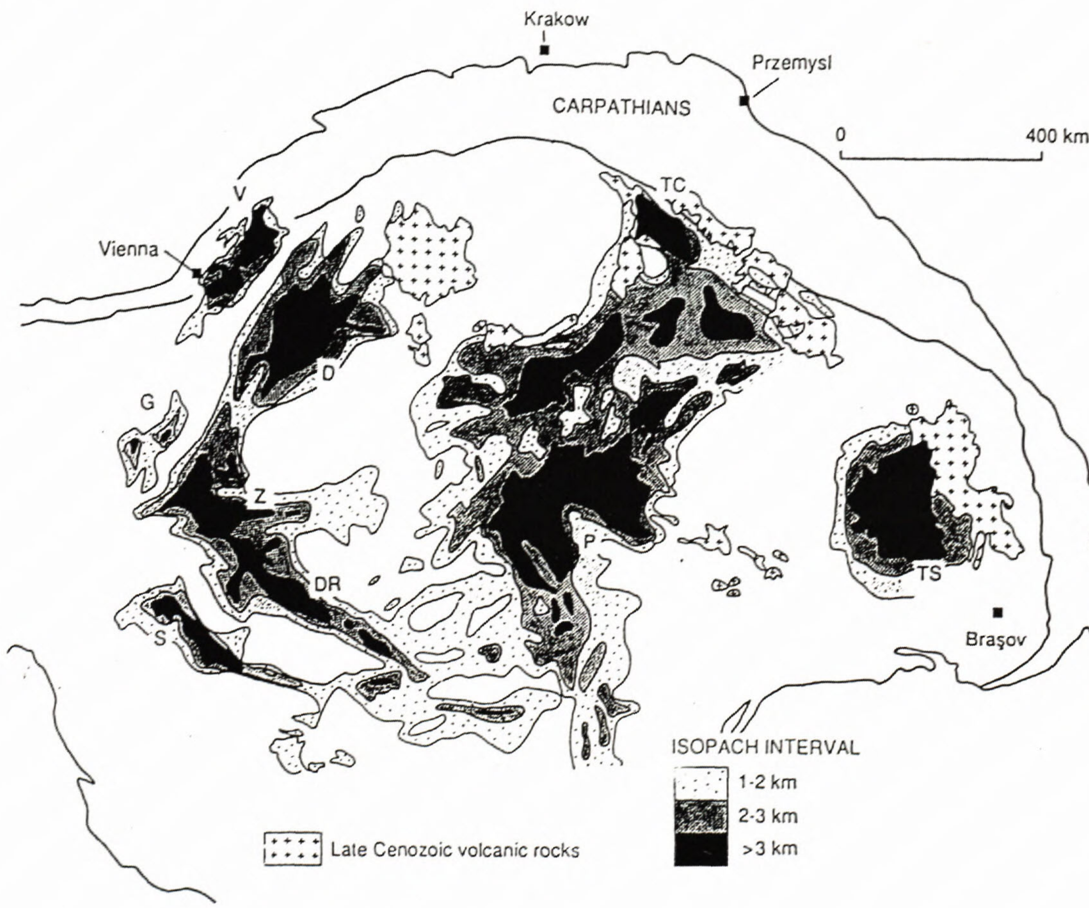



*Fig. 7 Izopachyte map of the Pannonian Basin system with subdivision into partial basins: S - Sava; Dr – Drava B; Z – Zala B; G – Graz B; D - Danube B; V - Vienna B; P - Pannonian s.s. B (Mako and Bekes Basins); Tc – Transcarpathian B; Ts - Transylvanian B (Royden et al., 1983)*

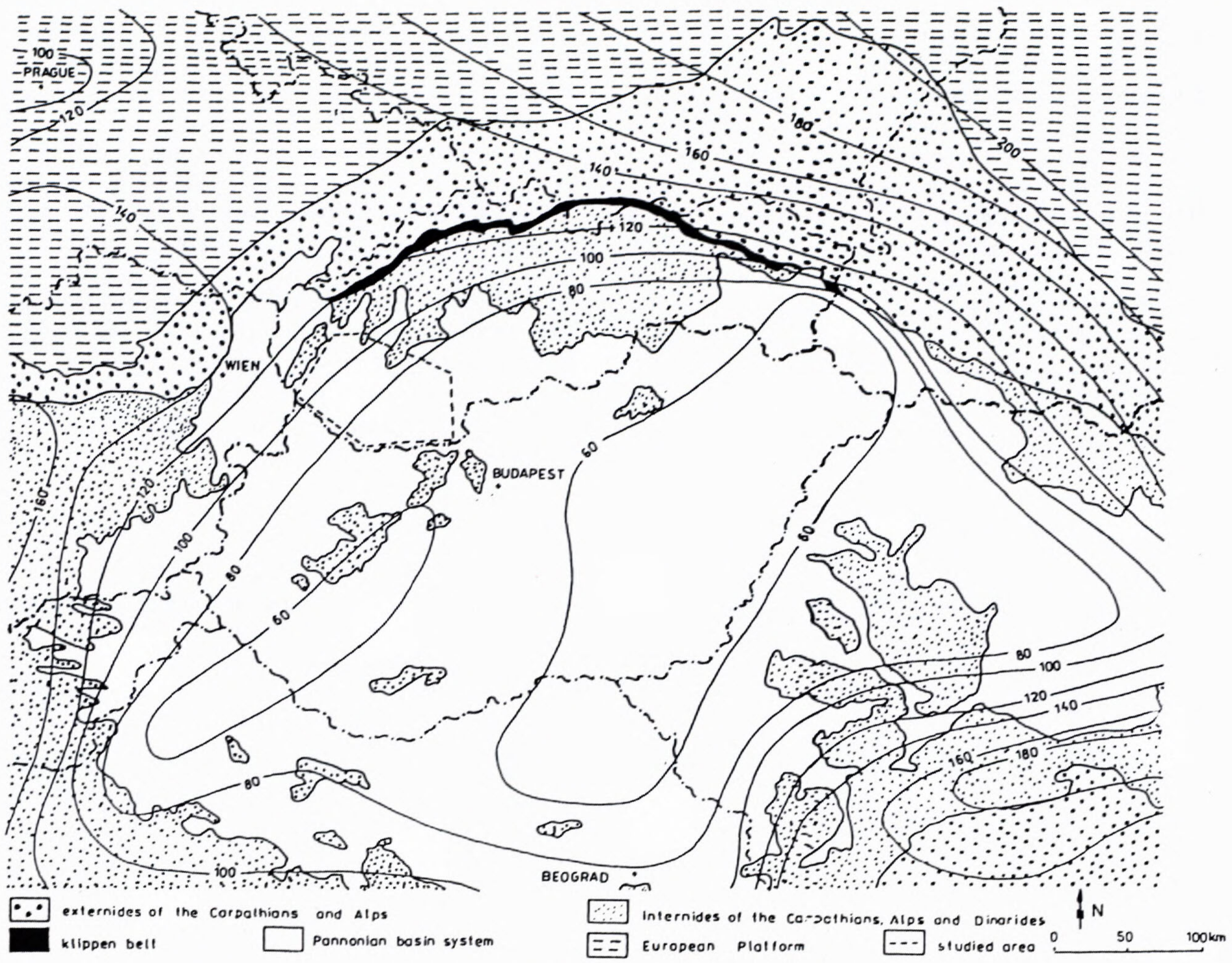



*Fig. 8 Lithospheric thickness map of the Pannonian Basin and surrounding territories (according to Horváth, 1993). Thicknesses are given in km.*

Eocene, Sotak et al. 1993), partial thrust planes are indicated on seismic profiles as subhorizontal or low-angle inclined conspicuous reflectors (Vozárová et al. 1993). During the Early and Middle Karpatian, when extension predominated in the East-Slovakian Basin (Fig. 4) at least a part of these thrust planes could act as listric faults along which partial tectonic units or slices of pre-Neogene basement were slided. As a result the East - Slovakian Basin had been opened and filled up by marine Teriakovce Formation, later by marine-lagoon evaporites of Soľná Baňa Formation (P. Kováč et al. 1994).

In the following process of rift stage and crustal extension next faults were activated. Conjugated systems of horizontal strike slips were opening smaller basins in the framework of the Pannonian area (Horváth and Royden 1981, Royden et al. 1982, Tari et al. 1992). Extension reaches 50% to 200% and it was a response of crust thinning when asthenosphere rising, rifting and postrift stage were situated more or less above each other.

## Discussion

### Model of asymmetric opening of the Danube Basin

Knowledge on structure of the northern part of the Danube Basin suggests different mechanism of the basin origin and basin filing as in other partial depressions of the Pannonian area. The substance of the difference is in fluctuation of crust and lithosphere thickness in the area of the Danube Basin. It also lies in contrasting thickness of syn- and postrift deposits, in subsidence velocity, in frequency of synsedimentary faults and size of their throw. In the area of Gabčíkovo Depression, e.g. in the central part of the Danube Basin, the crust thickness or the depth of MOHO is 27.5 km or less (Fig. 9) and the lithosphere thickness is about 80 km (Fig. 8). The thickness of Middle Miocene deposits of synrift stage (Badenian and Sarmatian) is several hundred meters (Adam and Dlabač 1969), maximum 1500 m as is confirmed also by later seismic profiles (Fig. 13), synrift sediment thickness distribution (Fig. 10) and subsidence curves of selected boreholes (Diakovce-1 and Kolárovo-2, Fig. 14). The greater part of deposits from the synrift stage is absent on the Kolárovo elevation: Sarmatian deposits lie on metamorphous rocks and granitoids of Veporicum. In places, where synrift deposits are thinned on the seismic profile we assume only Sarmatian deposits (Fig. 13). The density of mostly synsedimentary faults deforming synrift deposits is relatively lower comparing to the northern part of the basin. Higher throw amplitudes are rare. On the contrary the deposits of postrift or thermal stage (Pannonian to Pliocene) reach considerable thickness, e.g. the thickness south of Dunajská Streda is up to 5000 m (Fig. 11). It is mainly proved by seismic profiles because none of boreholes penetrated postrift deposits in places of their maximum accumulation. An important difference of subsidence during the deposition of syn- and postrift sediments are also proved by subsidence curves (Fig. 14). The postrift deposits are only slightly deformed by faults and throw amplitudes are small (Fig. 13).

The crust thickness toward the north from Gabčíkovo Depression increases from 27.5 km to 30 km (Fig. 9) and the lithosphere thickness is about 100 km (Fig. 8). The synrift stage sediment thickness in partial depressions, namely in Blatné Depression and Rišnovce Depression, exceeds 2 500 m and 2 000 m respectively (Fig. 10). Synrift deposits are deformed by a dense system of synsedimentary faults with high throw amplitudes (in order of hundred meters - Fig. 12). Postrift deposits are developed only rudimentary. Their thickness abruptly decrease toward the north. The thickness is several tens, maximum several hundreds meters on the northren margins of depression (Figs. 11 and 12).

The above mentioned evidence about_structural heterogenity of the Northern Danube Basin suggests that it is possible to apply Coward model of heterogeneous lithosphere thinning (Coward 1986) to elucidate the basin genesis. This model is a modified model of a simple shear (Wernicke 1981, 1985). According to Coward model stretching of the lower part of the lithosphere is concentrated beneath the much more extensive zone of upper crust extension (Fig. 15). New fault generation can diffuse to the area of the initial rift zone and in this way it can widen the zone of the stretching of the upper crust. The fault expansion or uppercrust stretching can be supported by older, slightly waning anizotropy or compositional layering within the crust. Old fault systems or thrust planes are rejuvenated.

The sedimentary basin originating by asymmetric crust extension has outer zone with the extension only in the upper part of the crust and inner zone, where the upper crust is extended by a factor $\beta$, while the lower crust is extended by a factor $\beta + \beta'$ to balance the extension of the upper crust on the basin margin. The extension and fault development are not symmetric. In the zone of the upper crust thinning initial e.g. synrift subsidence carries

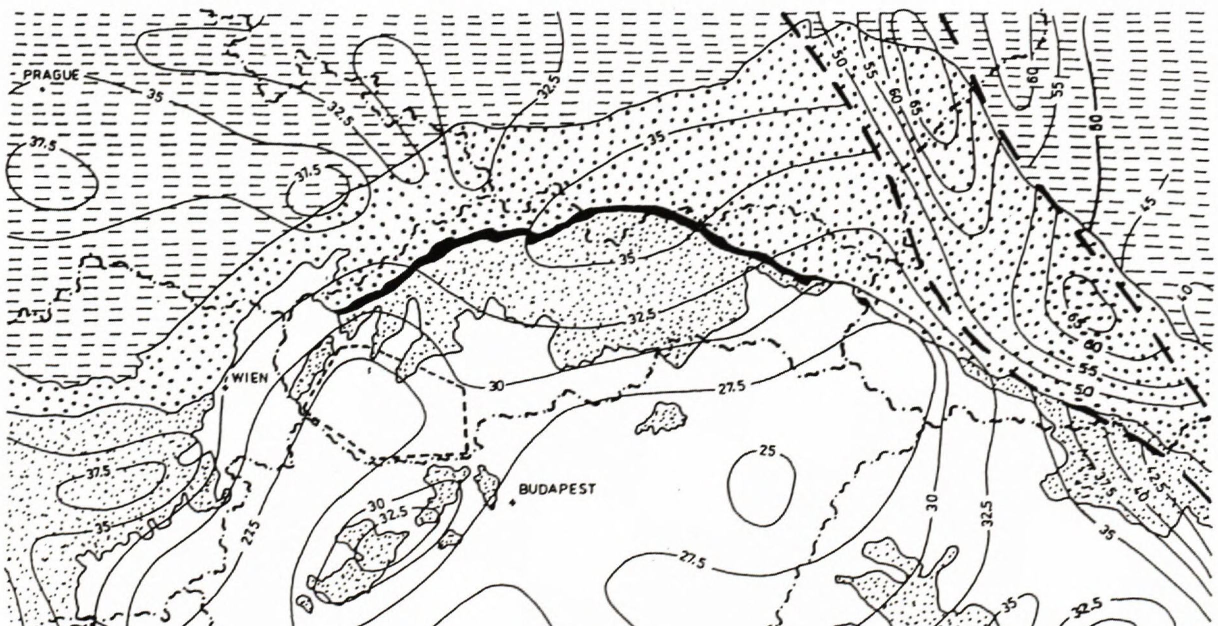



*Fig. 9 Crustal thickness map of the Pannonian Basin and surrounding territories (according Horváth, 1993). Thicknesses are given in km.*

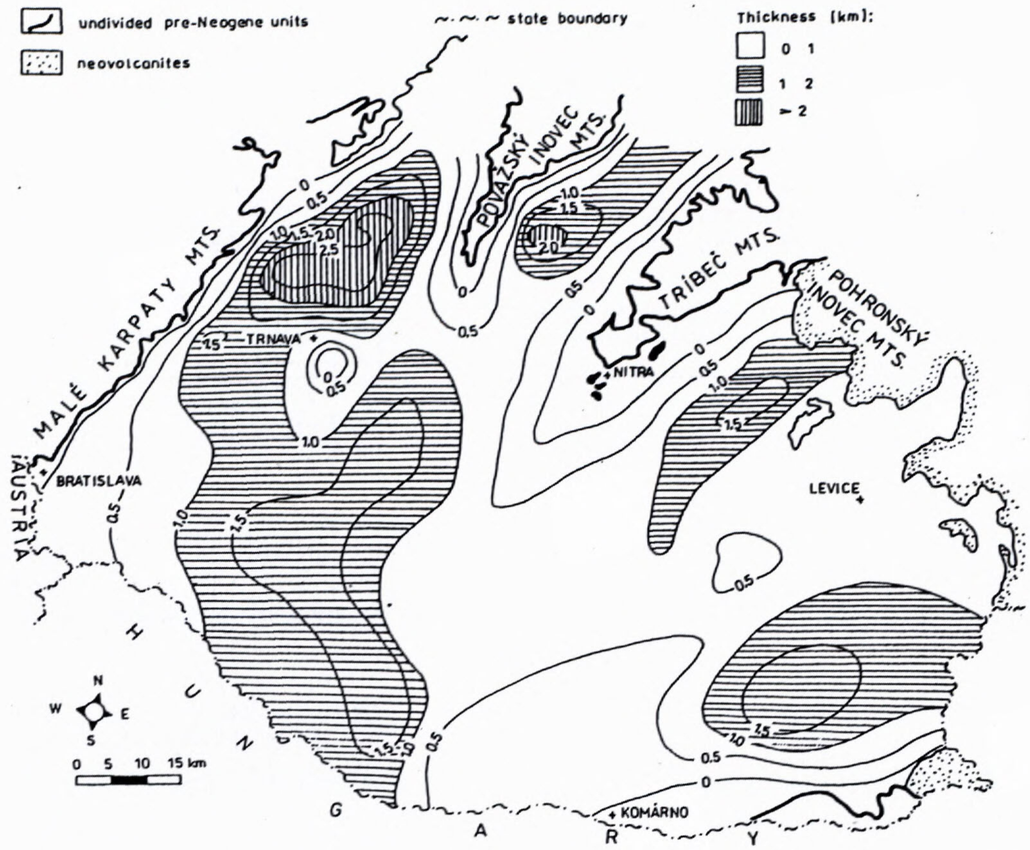



*Fig. 10 Northern part of the Danube Basin - Thicknesses are given in km. Maximal thickness is in the partial depressions near the northern Basin margin. See the area of Kolárovo elevation where the synrift sediments are thin and uncomplete*

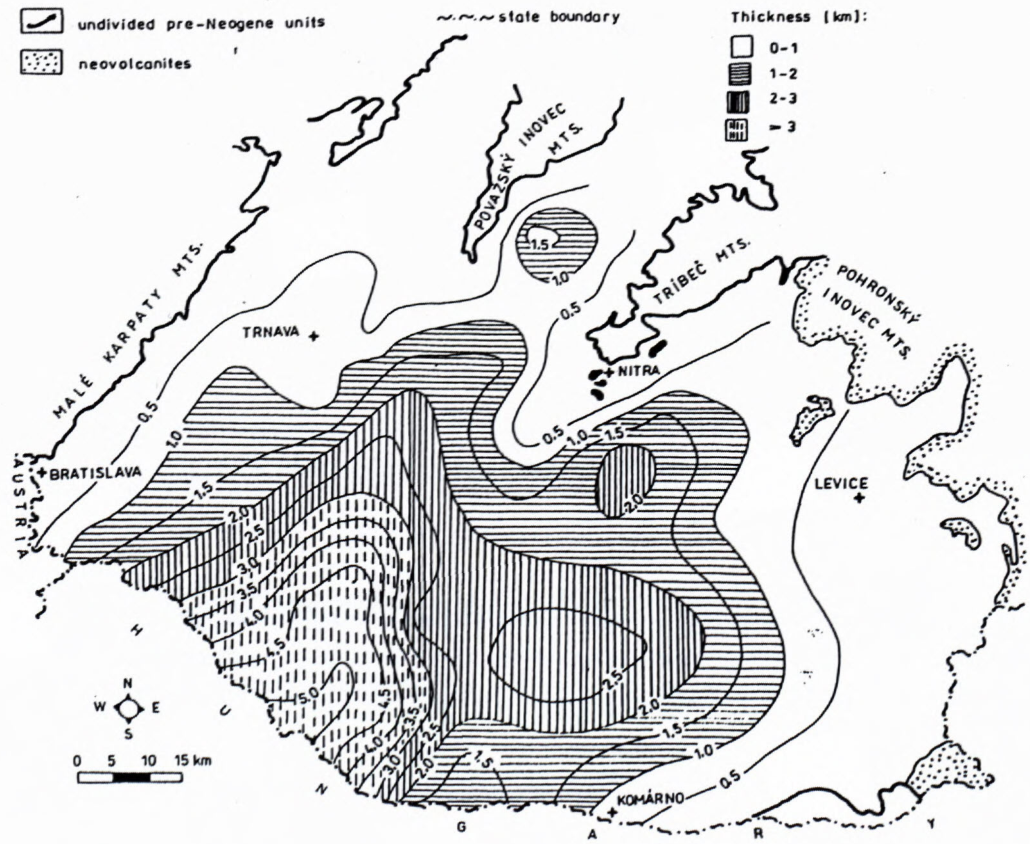



*Fig. 11 Northern part of the Danube Basin - Thickness map of the Pannonian, Pontian and Pliocene postrift deposits. Thicknesses are given in km. Maximal thickness is in Gabčíkovo depression.*

out. Thermal and/or postrift subsidence does not develope there (Fig. 15).

In the basin inner part where the entire lithosphere (inner zone) is thinning, both initial tectonic and subsequent thermal subsidence occur. The stretching of the whole crust by factor β triggers subsidence but the supplementary factor β′ in the lower crust and in the lithosphere mantle determines a slight uplift of lithosphere. If in the lower crust the density is variable, the total uplift occurs resulting in the emergence of the extensional upper crust above the sea level. In these conditions, initial subsidence of the inner zone has to be necessarily lower than in the outer zone. Besides, a discordance occurs between deposits of the initial subsidence and subsequent thermal subsidence. This discordance is often hidden and not conspicuous.

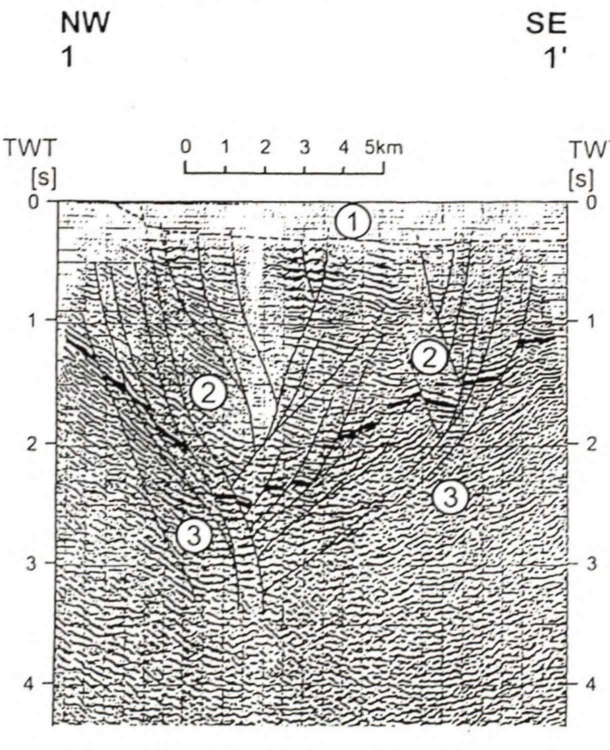
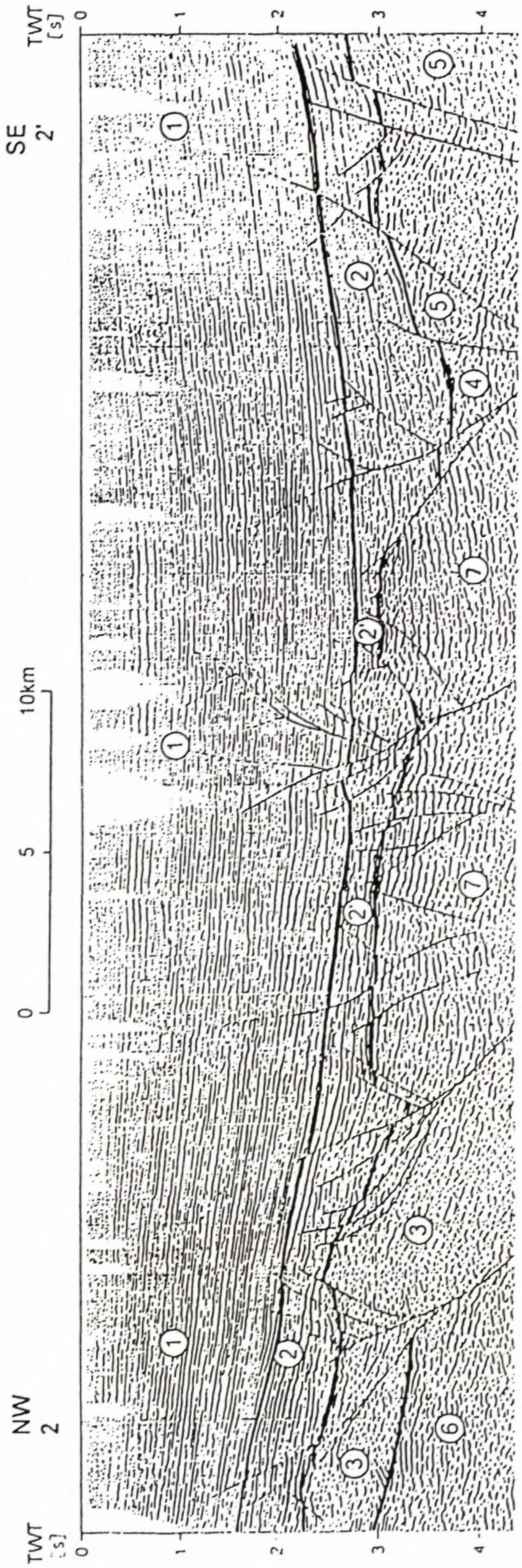



*Fig. 12 Migrated and interpreted seismic section from the Northwestern part of Danube Basin. The seismic line clearly shows the huge thickness of synrift deposits. The postrift deposits are severel times thinner.*

*1 –Sediments of postrift stage: Late Miocene (Pannonian and Pontian),interpreted according to the wells; 2 – Sediments of synrift stage: Uppermost Early and Middle Miocene (Karpathian, Badenian, Sarmatian); 3 – Basin floor units (Tatric).*

*Fig. 13 Migrated and interpreted seismic section from the Central part of Danube Basin. Seismic line shows reverse situation as Fig. 11. The postrift sediments are thick and synrift deposits several time thinner.*

*1 – sediments of postrift stage: late Miocene (Pannonian and Pontian), Pliocene (Dacian and Romanian), Quternary; 2 – sediments of synrift stage: middle Miocene (Badenian and Sarmatian); 2′–reduced thickness - Sarmatian only?; 3–7 – tectonic units of the basin floor; 3 – Tatric, 4 – Veporic, 5 – Bakony, 6 – Penninic?, 7 – Unknown.*



In the Danube Basin, the partial Blatné, Rišňovce, Komjatice or also Želiezovce depressions located in the northern part of the basin (Fig. 1) are consistent with the outer zone. In these depressions, asymmetric extension of the outer crust resulted in reactivation of faults active in the older depression structure. It determined tectonic subsidence governing a thick synrift pile of deposits. The later thermal subsidence was applied in very restricted extent. The postrift deposits occur only rudimentary.

Gabčíkovo Basin (Fig. 1) is consitent with the inner zone where synrift deposits of initial phase are substantially less thick than postrift deposits of thermal phase. Kolárovo anomaly suggests that in the beginning of the initial subsidence a local energic uplift occurred in the inner zone and crystalline rocks of basin basement were denuded. Only at the end of this phase elevation sank down and the deposits of the final part of the initial phase (Vrábel Formation - Sarmatian age) lie on it transgressively (Fig.13). In the thermal (postrift) subsidence stage the entire partial Gabčikovo Basin subsided uniformly.

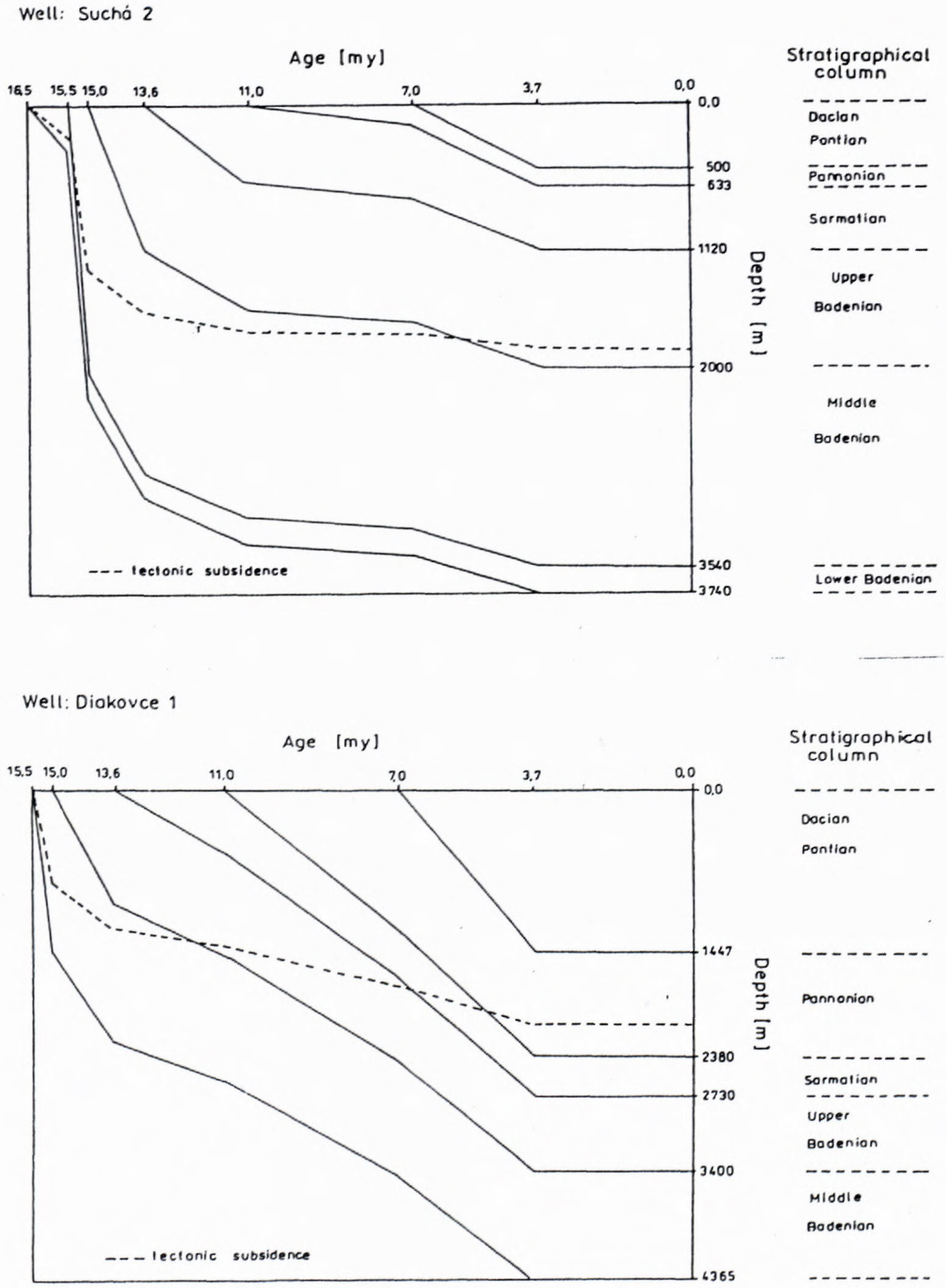



*Fig. 14*

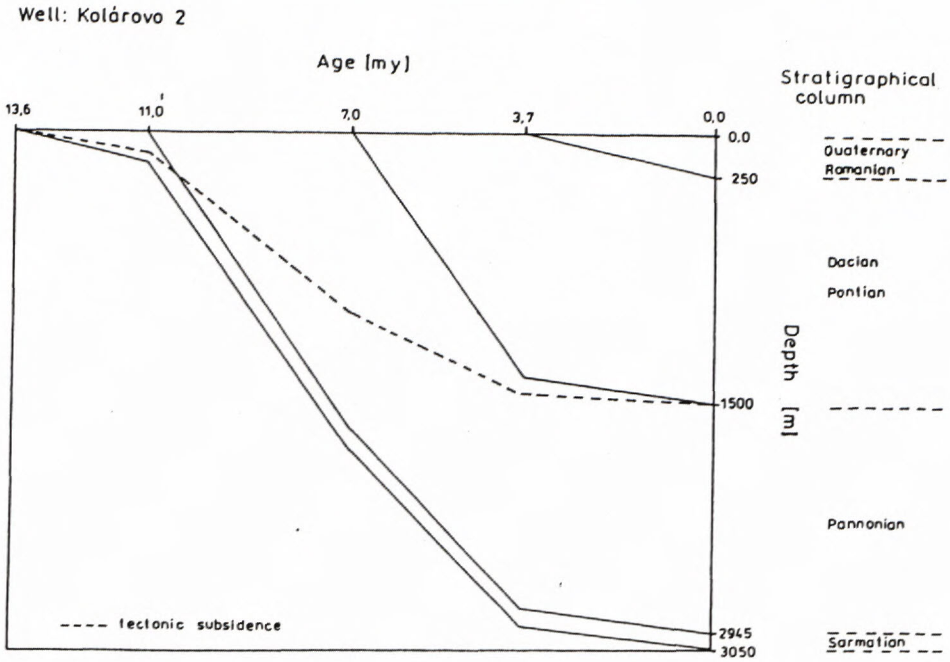



*Fig. 14 Burial history curves and tectonic subsidence in Northern part of Danube Basin. Modeled tectonic subsidence is the sum of initial and thermal subsidence. See well expressed initial subsidence in the well Suchá-2 and partly Diakovce-1 (Badenian and Sarmatian); in the well Kolárovo-2 initial subsidence is missing. Contrary, the thermal subsidence (Pannonian – Quaternary) is well expressed in the well Kolárovo-2, less expressed in the well Diakovce-1 and only rudimentary in the well Suchá-2.*

**The difference between Coward model of asymmetric crust stretching and Wernicke model of lithosphere extension by simple shear**

Coward model of asymmetric crust stretching or heterogeneous stretching descends from Wernicke model of lithosphere extension by a simple shear but it is not entirely consistent with this model. The subsidence in Wernicke model is associated with slightly inclined shear zone penetrating the whole crust and stretching out as far as to mantle. The extension from the upper crust in one area should be transferred to the lower crust and lithospheric mantle in the other area by the shear zone. The extensional basin is developing on the site of the upper crust extension controlled by faults. Thus, Wernicke model in contrast to the Coward model and structure of the northern part of the Danube Basin assumes upper crust thinning and subsequent initial tectonic subsidence only in the outer zone. In places where the lower crust and mantle lithosphere undergoe thinning and is not affected by faults the uplift occurs (discrepancy zone). The asthenosphere cooling beneath the zone of discrepancy induces return of the crust into initial position. The discrepancy zone sank below the original level in older zones of the crust extension by a simple shear. This results in formation of shallow, simple sag basin type without interaction of extension faults (Fig. 16).

On the contrary, Coward model does not assume huge shear penetrating the entire lithosphere and reaching the mantle.

The thinning of the upper crust and subsequent initial tectonic subsidence occurred in the whole area under extension e.g. in both outer and inner zones, even if in the inner zone it was less intensively. The subsequent thermal subsidence affected by a significant extent the central zone, resulting in several thousand meters thick pile of deposits in the case of the Danube Basin.

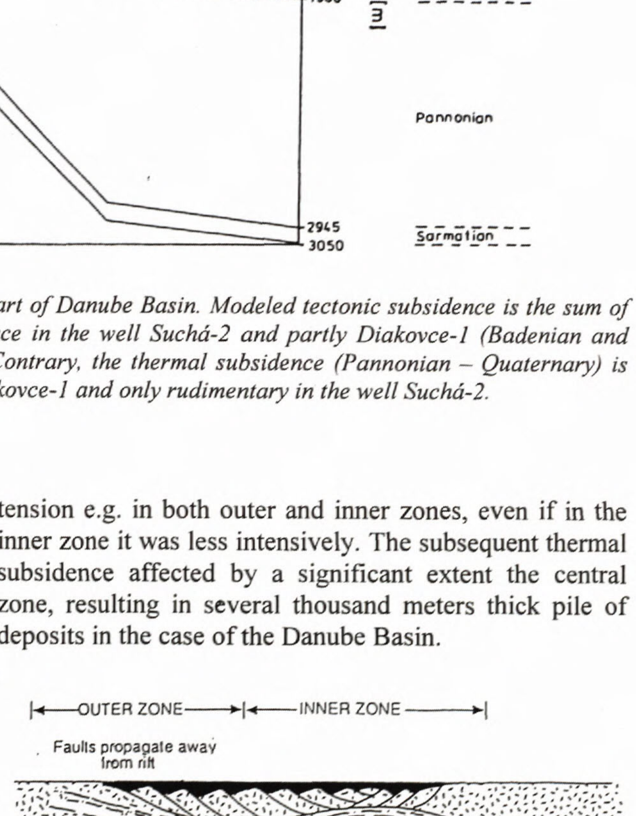



*Fig. 15 Heterogeneous thinning of the lithosphere (after Coward, 1986). The upper crustal extension spread outwards asymmetrically over a wide region, possibly reactivating previous tectonic fabrics. The lower crust and subcrustal lithosphere, however, are shown extendind over a much smaller region. This lower crustal/subcrustal thinning may produce thermal domes and erosional unconformities and older extensional faults may be inverted.*

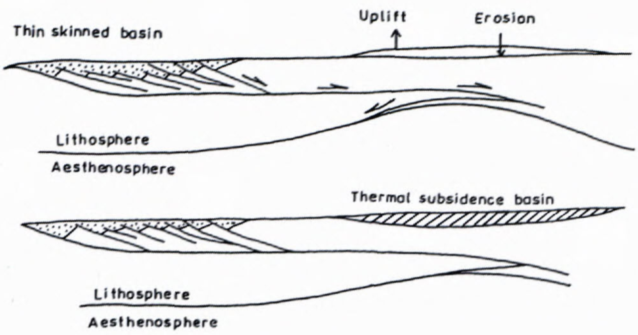



*Fig. 16 The model for crustal stretching on a low angle shear zone (after Wernicke, 1981, 1985 – modified).*

## Conclusion

Coward model of heterogeneous lithosphere thinning most conspicuously elucidates mechanism of the openning and filling of the Northern Danube Basin or its northern part. The basin has two conspicuously separated zones:

- Outer zone with the initial subsidence determined by the upper crust thinning. The important role played rejuvenated or new formed faults. The thermal subsidence was unconspicuous, substantially lesser than preceding initial subsidence.

- Inner zone with manifestation of initial and thermal subsidence. The initial subsidence was less intensive than thermal one. Uplift occurred locally during the subsidence. The thermal subsidence took relatively large area of the basin where it enables formation of several meters thick sediment pile but it stretched into the outer zone only marginally.

## References

Adam Z., Dlabač M., 1969: Vysvětlivky k mapám mocnosti a litofaciálního vývoje Podunajské nížiny. *Záp. Karpaty* 11, Bratislava, 156-172

Andrusov D., 1968: Grundriss der Tektonik der Nördlichen Karpaten. Slov. Akad. vied, Bratislava, 1-187

Allen Ph.A., & Allen J.R., 1992: Basin analysis, principles and applications. Blackwell Scient. Publ., London, 1-451

Beaumont C., Keen C.E., & Boutilier 1982: On the evolution of rifted continental margins, comparison of models and observations for Nova Scotia margin. *Geophys. J. R. astr.* Soc. 70, 667-715

Burke K., & Sengör A.M.C., 1986: Tectonic escape in the evolution of the continental crust. In M. Barazangi & L. Brown (edts.): Reflection Seismology a global perspective. Amer. Geophys. union *Geodynamics* Series 14, 41-53

Csontos L., Nagymarosy A., Horváth F. & Kováč M., 1992: Tertiary evolution of the Intra-Carpathian area: a model. *Tectonophysics* 208, 2221-2241

Coward M.P., 1986: Heterogenous stretching, simple shear and basin developement. Earth planet. *Sci Letters* 80, 325-336

Császar G., & Haas J., (edts.) et al., 1983: Magyarország litosztratigráfiai formációi. Hung. Geol. inst. Budapest

Čechovič V., 1952: Geológia juhoslovenskej panvy. *Geol. Práce, Zoš.* 33, Bratislava, 1-53

Dewey, J.F., 1988: Extension collapse of orogens. *Tectonics* 7, 1123-1139

Hámor G., Ravaszné Baranyai L., Balogh K., Árva Soós E., 1980: A magyarországi miocén ryolittufa-szintéK radiometrikus kora. *Évi jelentése* 1978, Hung. Geol.Inst., Budapest, 65-72

Hámor G., et al., 1988: Neogene paleogeographic Atlas of Central and Easterm Europe. Hung. Geol. Inst. Budapest

Haq B.U., Hardenbol J. & Vail P. R., 1987: Chronology and fluctuationg sea levels since the Triassic. *Science*, v. 235, 1156-1167

Heilinger S.J. & Sclater J.G., 1983: Some comments on two - layer extensional models for the evolution of sedimentary basins. *J. geophys*. Res. 88, 8251-8270

Horváth F., & Royden L., 1981: Mechanism for the formation of the Intra - Carpathian Basin: A review. *Earth Evol. Sc.* 3-4/1981, Vieweg, Braunschweig, 307-316

Horváth F., 1993: Towards a mechanical model for the formation of the Pannonian basin. *Tectonophysics*, 226, 333-357

Horváth F. & Brckhemer H., 1982: Mediterranean backarc basins. In: H. Berckhemer and K. Hsú (edts.), Alpine-Mediterranean Geodynamics. AGU *Geodyn.* Ser., 7: 141-173

Jiříček,R. 1979: Tektogenetický vývoj karpatského oblouku během oligocénu a neogénu. In: Maheľ, M. (edt.): Tektonické profily Západných Karpát. GÚDŠ, Bratislava, 205-214.

Kázmér M.& Kovács, S., 1985: Permian-Paleogene paleogeography along the Eastern part of the Insubric-Periadriatic Lineament system: evidence for continental escape of the Bakony-Drauzug Unit. *Acta geol. Acad. Sci. hung.* (Budapest),.281/2), 71–84.

Kováč P., Vass D., Janočko J., Karoli S.& Kaličiak M., 1994: Tectonic history of the East Slovakian Basin during the Neogene. ESRI Occasional Publication, New Series No.11 A-B, Columbia SC., 1-15

Lyon - Caen H., & Molnár P., 1989: Constrains on the deep structure and dynamics processes beneath the Alps and adjacent regions from an analysis of gravity anomalies. *Geophys.* J. Int. 99, 19-32

Márton E., Vass D., & Túnyi I., 1995: Mladoterciérne rotácie megajednotky Pelso a priľahlých častí Západných Karpát. *Knihovička Zemní plyn a Nafta* 16, Hodonín, 97-108

McKenzie D. P., 1978: Some remarks on the developement of sedimentary basins. *Earth planet. Sci Letters* 40, 25-32

Molnar P.& Lyon-Caen H., 1988: Some simple physical aspects of the support, structure, and evolution of mountain belts. In: S.P.Clark Jr., B.C.Burchfiel & J.Suppe (edts): Processes in continental lithospheric deformation. *Geol. Soc. Am. Spec. Pub.*, 218, 179-207.

Osczcypko N. & Slaczka A., 1985: An attempt to palimspastic reconstruction of Neogene basins in the Carpathian Foredeep. Ann. societ. Geologorum Poloniae, rocn. Polsk. Towar. *Geologiczsnego.* 55-1/2, Kraków, 55-75

Ratschbacher L., Merle O., Davy P. & Cobbold P., 1991a: Lateral extrusion in the Eastern Alps, Part 1: boundary conditions and experiments scaled for gravity. *Tectonics*, 10 (2): 245-256

Ratschbacher L., Frisch W., Linzer H.G. & Merle O., 1991b: Lateral extrusion in the Eastern Alps. Part 2: structural analysis. *Tectonics*, 10 (2): 257-271

Royden L. & Keen C.E., 1980: Rifting proces and thermal evolution of the continental margin of Eastern Canada determinated from subsidence curves. *Earth planet. Sci. Letters* 51, 343-361

Royden L.H., Horváth F. & Burchfiel B.C., 1982: Transform faulting, extension and subduction in the Carpathian Pannonian region. *Geol. Soc. Am. Bull.* 93, 717-725

Royden L., Horváth F. & Rumpler J., 1983: Evolution of the Pannonian basin system 1. Tectonics. *Tectonics* 2/1, 63-90

Royden L.H. & Horváth F.,(edts.) 1988: The Pannonian Basin, study in Basin evolution. *Am. Ass. Petrol. Geol. Mem.* 4-5, Tulsa, U.S.A. 1-394

Seneš J., 1952: Štúdium o akvitánskom stupni. *Geol. Práce, Zoš. 31*, Bratislava, 1-75

Steininger F.F., Műller C. & Rögl F., 1988: Correlation of Central Paratethys Eastern Paratethys and Mediteranean Neogene stages. *Am. Ass. Petrol. Geol. Mem.*,45:79-88

Soták J., Rudinec R. & Spišiak J.,1993: The Penninic "pull-apart" dome in the pre-Neogene basement of the Transcarpathian depression (Eastern Slovakia). *Geol. carpathica* 44, Bratislava, 11-16

Škvarka Ľ., Vass D., Ondrejičková A. & Elečko M., 1989: Nové poznatky o južnej časti strhársko-trenčskej prepadliny. *Správy o geol. výskumoch* 25, Geol. Úst. D. Štúra, Bratislava, 65-69

Tari G., Báldi T. & M. Báldi-Beke 1992: Paleogene retroarc flexural basin beneath the Neogene Pannonian Basin: A geodynamic model. *Tectonophysics* 226, 433-455

Tari G., Horváth F. & J.Rumpler 1992: Styles of extension in the Pannonian Basin. *Tectonophysics* 208, 203-219

Vass D., 1976: Molasové panvy a globálno-tektonický model Karpát. Zborník referátov vedeckej konferencie: Československá geológia a globálna tektonika (Smolenice 1976). Edičné stredisko Geol. Úst. D. Štúra, Bratislava, 111-117

Vass D., 1979: Genesis of innermolasse basins in West Carpathians in light of leading function of mantle in earth's crust development. In M. Maheľ & P. Reichwalder (edts.): Czechoslovak geology and global tectonics, Veda SAV, Bratislava, 183-197

Vass F., Konečný V. & Šefara J., et al., 1979: Geologická stavba Ipeľskej kotliny a Krupinskej planiny. GÚDŠ, Bratislava, 1-280

Vass D., Elečko M., Kantorová V., Lehotayová R. & Klubert J., 1987: Prvý nález morského otnangu v juhoslovenskej panve. *Mineralia slov.* 19/5, Bratislava, 417-422

Vass D., Stránik Z., & Krystek I., 1987: Tectonomagmatic activity in the West Carpathians (Czechoslovak part) from Pyrenean to Rhodanian epochs.

Yu. G. Leonov & V.E.Khain: Global correlation of tectonic movements. J. Wiley & sons Chichester., 159-171

Vass D., Kováč M., Konečný V. & Lexa J., 1988: Molasse basins and volcanic activity in West Carpathian neogene - its evolution and geodynamic character. *Geol. Zborník - Geol. carpathica* 39/5, Bratislava, 539-561

Vass D. & Elečko M., et al., 1992: Vysvetlivky ku geologickej mape Lučenskej kotliny a Cerovej vrchoviny 1:50 000 Geol. Úst. D. Štúra, Bratislava, 1-196

Vass D., Hók J., Kováč P. & Elečko M., 1993: Sled paleogénnych a neogénnych tektonických udalostí v juhoslovenských kotlinách vo svetle napäťových analýz. *Mineralia slovaca* 25, Bratislava, 79-92

Vozárová A., Vozár J., Tomek Č., Rakús M. & Kováč P., 1993: Reinterpretácia podložia Východoslovenskej panvy a jej korelácia s jednotkami Karpát. Manuskript, GS SR, Bratislava

Wernicke B., 1981: Low-angle normal faults in the Basin and Range Province - nappe tectonics in an extending orogen. *Nature* 291, 645-648

Wernicke B., 1985: Uniform sense simple shear of the continental lithosphere. *Can. J. Earth* Sci 22, 108-125

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Matula M., 1969: Regional engineering geology of Czechoslovak Carpathians. 1. Ed. Maheľ, M., Bratislava, Vyd. Slov. Akad. Vied, 225 p.

Andrusov D., Bystrický J. & Fusán O., 1973: Outline of the Structure of the West Carpathians. Guide-book for geol. exc. X. Congr. CBGA, Geol. Úst. D. Štúra, Bratislava, 5 - 44.

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  7. publishing house
  8. page range
  9. non published reports should be denoted "manuscript" and the place of archive should be given.

Proofs

The translator as well as the author(s) are obliged to correct the errors which are due to typing and technical arrangements. The first proofs are sent to author(s) as well as to the translator. The second proof is provided only to the editorial office. It will be sent to authors upon request.

The proofs must be marked clearly and intelligibly, to avoid further errors and doubts. Common typographic symbols are to be used, the list and meaning of which will be provided by the editorial office. Each used symbol must also appear on the margin of the text, if possible on the same line where the error occurred. The deadlines and conditions for proof-reading shall be stated in the contract.

Final remarks

These instructions are obligatory to all authors. Exceptions may be permitted by the Editorial Board or the managing editor. Manuscripts not complying with these instructions shall be returned to the authors.

1. Editorial Board reserves the right to publish preferentially invited manuscript and to assemble thematic volumes,

2. Editorial Board sits four times a year and closing dates for individual volumes will be on every 15th day of March, June, September and December.

3. To refer to one Magazine please use the following abbreviations: Slovak Geol. Mag. No. .... D. Štúr Publ. Bratislava.